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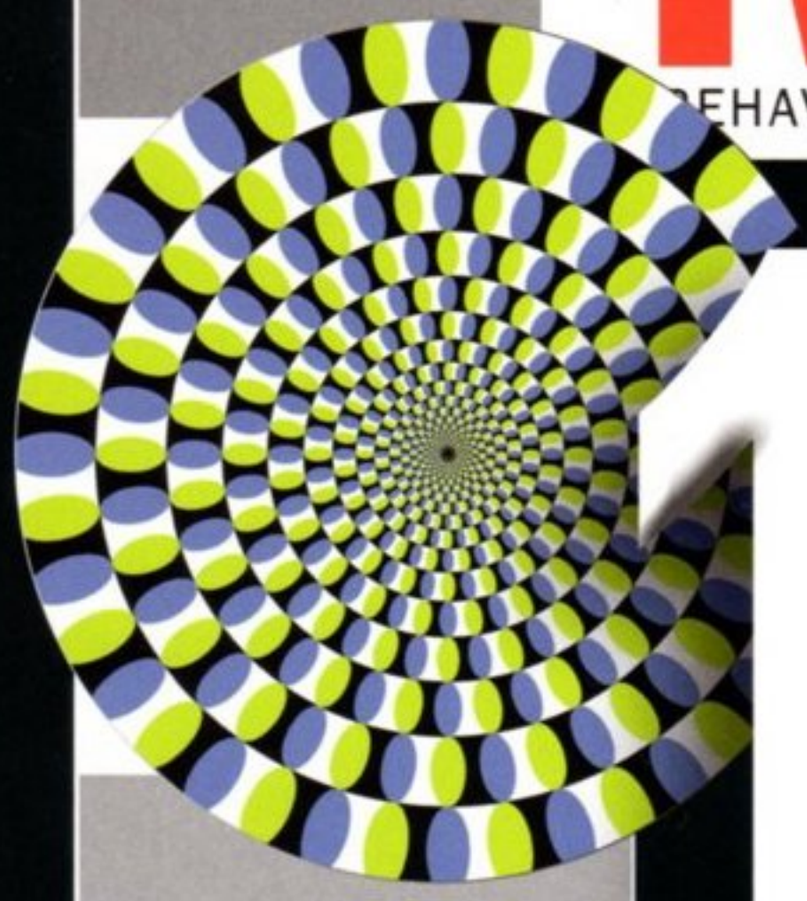
SCIENTIFIC AMERICAN MIND

BEHAVIOR • BRAIN SCIENCE • INSIGHTS



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SCIENTIFIC AMERICAN MIND
BEHAVIOR • BRAIN SCIENCE • INSIGHTS

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Is Seeing Believing?

Reality is merely an illusion, albeit a very persistent one. —Albert Einstein

What we experience shapes our reality. "Seeing is believing," right? Not necessarily. Visual illusions can distort our perception so that what we "see" does not correspond with what is physically there. This special edition of *Scientific American Mind* explores the world of sensory illusions and delves into how they fool the brain.

The word "illusion" derives from the Latin *illudere,* "to mock," whereas the word itself has roots in 14th-century Anglo-French, meaning an act of deception. That's because our brain—not our eyes—is the final arbiter of "truth." We are wired to analyze the constant flood of information from our senses and organize that input into a rational interpretation of our world. Much of the time our brain decodes those signals correctly. But illusions derail the process—although our sensations may seem to be accurate, our perceptions are not. Some illusory adaptations help us to survive, such as being able to recognize the same object outside in bright sun or in a dimly lit room, despite the difference in brilliance or wavelength of the light source. Others just trick us. Illusions are both intriguing and fun; our deep fascination with them dates back to the ancient Greeks. For the past century, however, they have also played an important role in brain research.

Illusions help neuroscientists unravel the mysteries of how the human brain creates "reality." In the opening article of this special issue, Susana Martinez-Conde and Stephen L. Macknik write, "It is a fact of neuroscience that everything we experience is a figment of our imagination." Understanding how the brain "misperceives" sensory input and influences perception is at the heart of their research in their respective roles as directors of the Laboratory of Visual Neuroscience and of the Laboratory of Behavioral Neurophysiology at the Barrow Neurological Institute in Phoenix. In the articles that fill these pages, Martinez-Conde and Macknik will show you how your brain constructs 3-D images, how context can alter the way you gauge size and perceive color, perspective or pain—and share illusions that make objects appear, disappear or move.

If you want more eye candy, click through the past winners of the Best Illusion of the Year Contest. Martinez-Conde and Macknik run the Neural Correlate Society, which hosts the annual competition (illusionoftheyear.com). This year's event, sponsored by the Mind Science Foundation and *Scientific American,* was held in May at the Philharmonic Center for the Arts in Naples, Fla. And don't forget to notice the biggest illusion of all: the world around you.

Sharon Guynup
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SCIENTIFIC AMERICAN MIND Volume 25, Number 3, Fall 2016

SPECIAL EDITION

ILLUSIONS: 187 WAYS TO TRICK YOUR BRAIN

BY SUSANA MARTINEZ-CONDE AND STEPHEN L. MACKNIK

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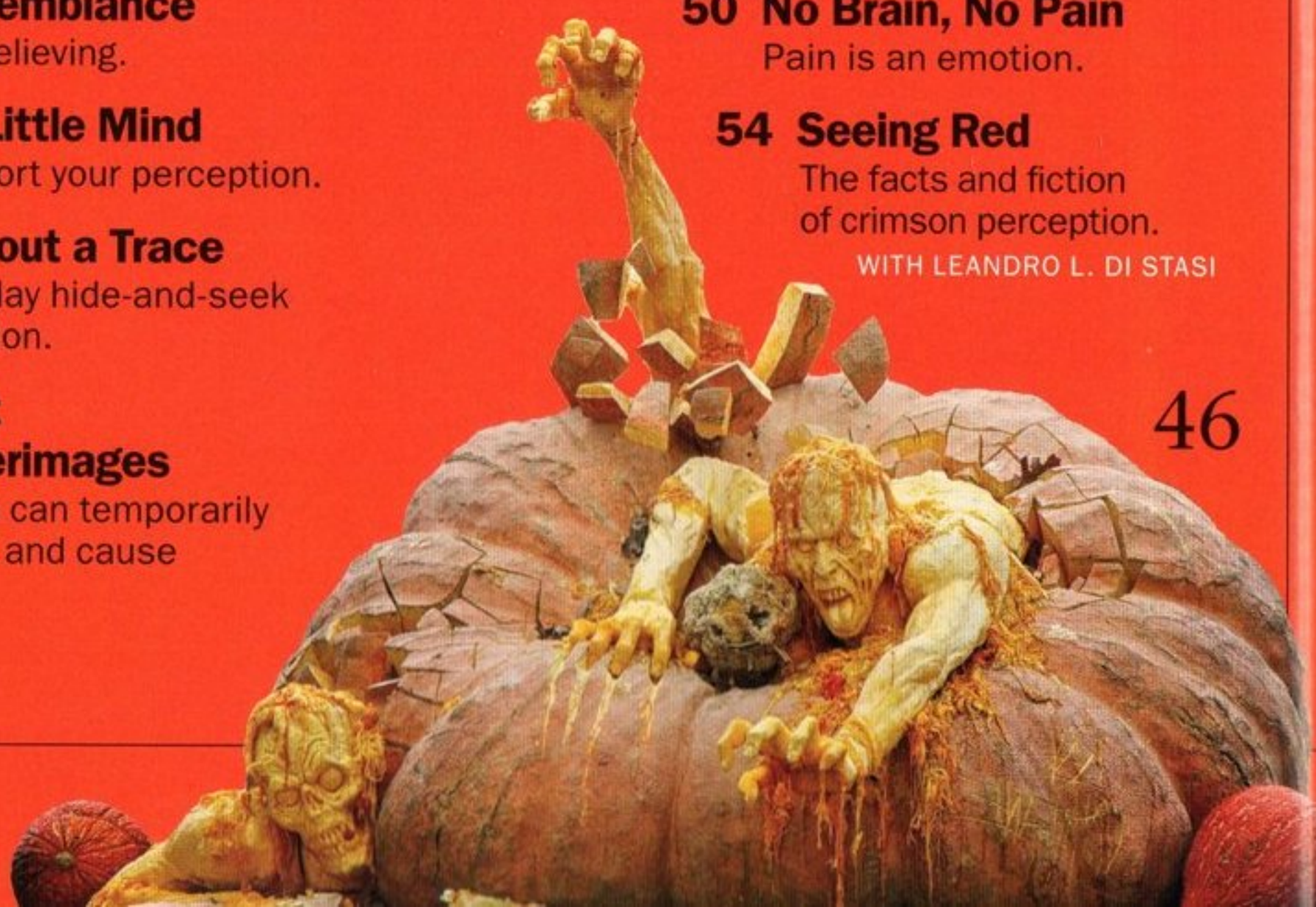

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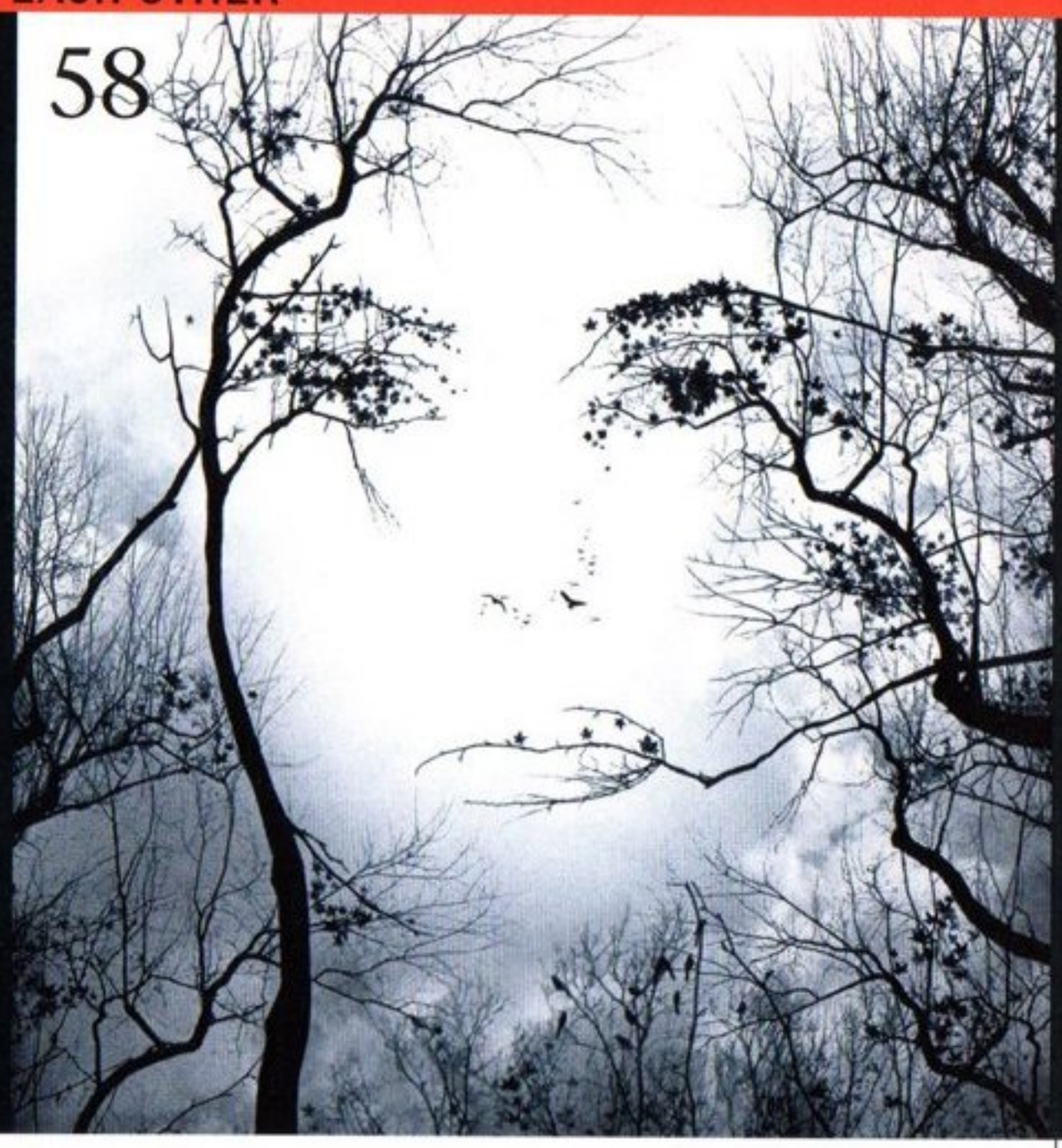

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Articles in this special issue are updated from previous issues of *Scientific American Mind*.

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What It Means to Be You

You are more than a robot searching for food and mates

By Susana Martinez-Conde and Stephen L. Macknik

Is not this whole world an illusion? And yet it fools everybody.
—Angela Carter, English novelist (1940–1992)

We are our nervous system. Our brain "drives" our body in an evolutionary quest for food and mates. If you could remove parts of your nervous system one by one, what minimal set would need to remain for you to still be *you?* Quadriplegic patients don't lose consciousness or emotions, despite spinal cord damage interrupting the brain signals to their limbs and torso. Your spinal column is not critical to who you are. Brain damage from stroke or trauma can cause the inability to see, hear or smell, but these sensory deficits do not affect our fundamental sense of self.

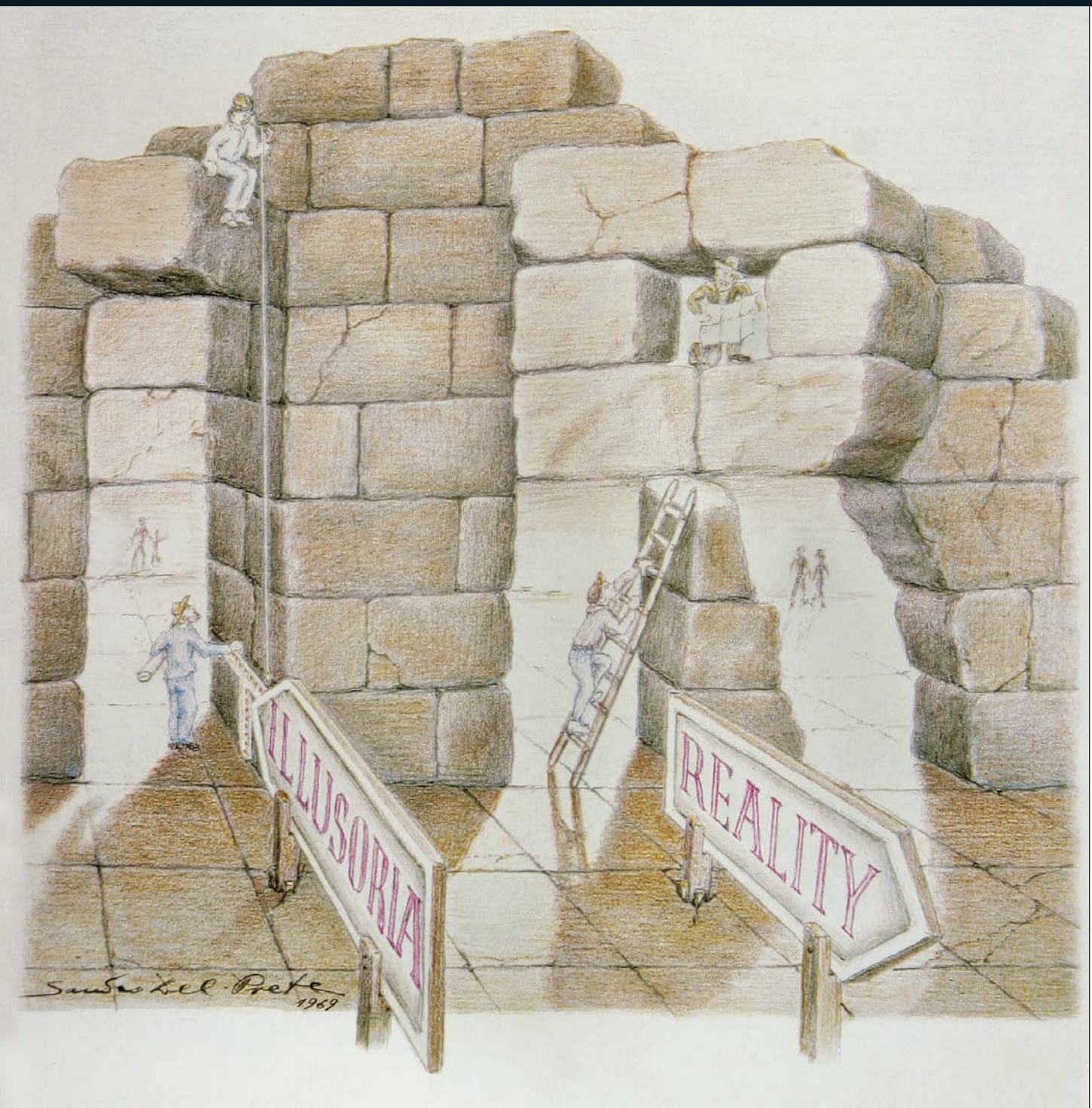
If you took a neuron, put it in a dish and nourished it (as many neuroscientists, including us, have done), you would find that it hums along and lives its life just fine as long as the environmental conditions remain favorable. It will even form circuits, connecting with other neurons you stick in the dish. Drop in some glutamate, the most common neurotransmitter in the brain, and the neuron will excitedly fire off a volley of impulses. But did it *intend* to fire? Did it consciously decide to express its delight, like a tiny gourmand tasting a delicacy by its favorite chef? Or did the neuron act as any inanimate machine might, like a heliotropic blade of grass following the sun across the sky?

Let's put that neuron back in the brainpan, which, by the way, is just a dish that will nourish it and keep the conditions favorable. That cell will form specific connections and microcircuits that somehow result in conscious feeling. Those circuits are now animate, just like those underlying the first-person experience of your life. How can that be?

The answer is that we don't know. Sorry, but this is what research is about: if we knew the answer, we would be *historians* rather than scientists. What we do know is that everything you have ever seen, heard, felt or thought was experienced by neurons in your brain, which is a natural miracle in and of itself. Neurons gather information from your senses, intellect and memory and so create a grand simulation of the world around you, forming the basis of your entire consciousness and subjective universe. How neural circuits create conscious awareness from insentient neurons is perhaps the most important question in science. So how do we answer it?

When we experience an illusion, our perception fails to match the physical reality. This key dissociation makes illusions a powerful tool to isolate the critical brain areas that give rise to our sentience. It allows scientists like us to discriminate among the neural circuits processing information about reality versus our perception of that reality. Neuronal responses that correlate to the physical reality of an object (such as its physical luminance) and not to our perception of it (such as its illusory brightness) cannot be responsible for our conscious experience. The best way to figure out how our brain constructs our experience of the universe is, ironically, by studying illusory perception. In this issue are our best examples of the twisted, bizarre and truly weird illusions that help us understand who we are.

SANDRO DEL-PRETE (*top*); COURTESY OF GARY ARMSTRONG (*bottom*)



(About the Authors)

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THE Neuroscience OF ILLUSION

By Susana Martinez-Conde and Stephen L. Macknik

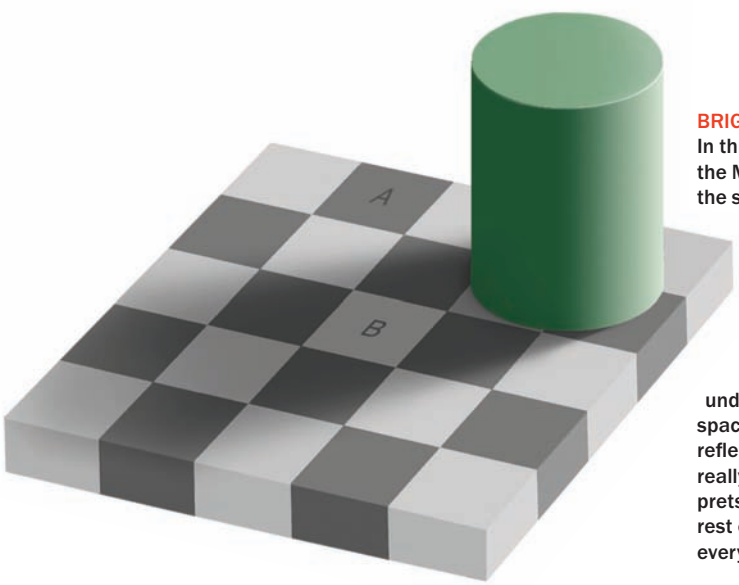
How tricking the eye reveals the inner workings of the brain

It is a fact of neuroscience that everything we experience is a figment of our imagination. Although our sensations feel accurate and truthful, they do not necessarily reproduce the physical reality of the outside world. Of course, many experiences in daily life reflect the physical stimuli that send signals to the brain. But the same neural machinery that interprets inputs from our eyes, ears and other sensory organs is also responsible for our dreams, delusions and failings of memory. In other words, the real and the imagined share a physical source in the brain. So take a lesson from Socrates: "All I know is that I know nothing."

One of the most important tools used by neuroscientists to understand how the brain creates its sense of reality is the visual illusion. Historically, artists as well as researchers have used illusions to gain insights into the inner workings of the visual system. Long before scientists were studying the properties of neurons, artists had devised a series of techniques to deceive the brain into thinking that a flat canvas was three-dimensional or that a series of brushstrokes was indeed a still life.

Visual illusions are defined by the dissociation between the physical reality and the subjective perception of an object or event. When we experience a visual illusion, we may see something that is not there or fail to see something that is there. Because of this disconnect between perception and reality, visual illusions demonstrate the ways in which the brain can fail to re-create the physical world. By studying these failings, we can learn about the computational methods used by the brain to construct visual experience.

Brightness, color, shading, eye movement and other factors can have powerful effects on what we "see." In this series of images, we showcase several basic categories of visual illusions and what they can teach us about perception in the brain.

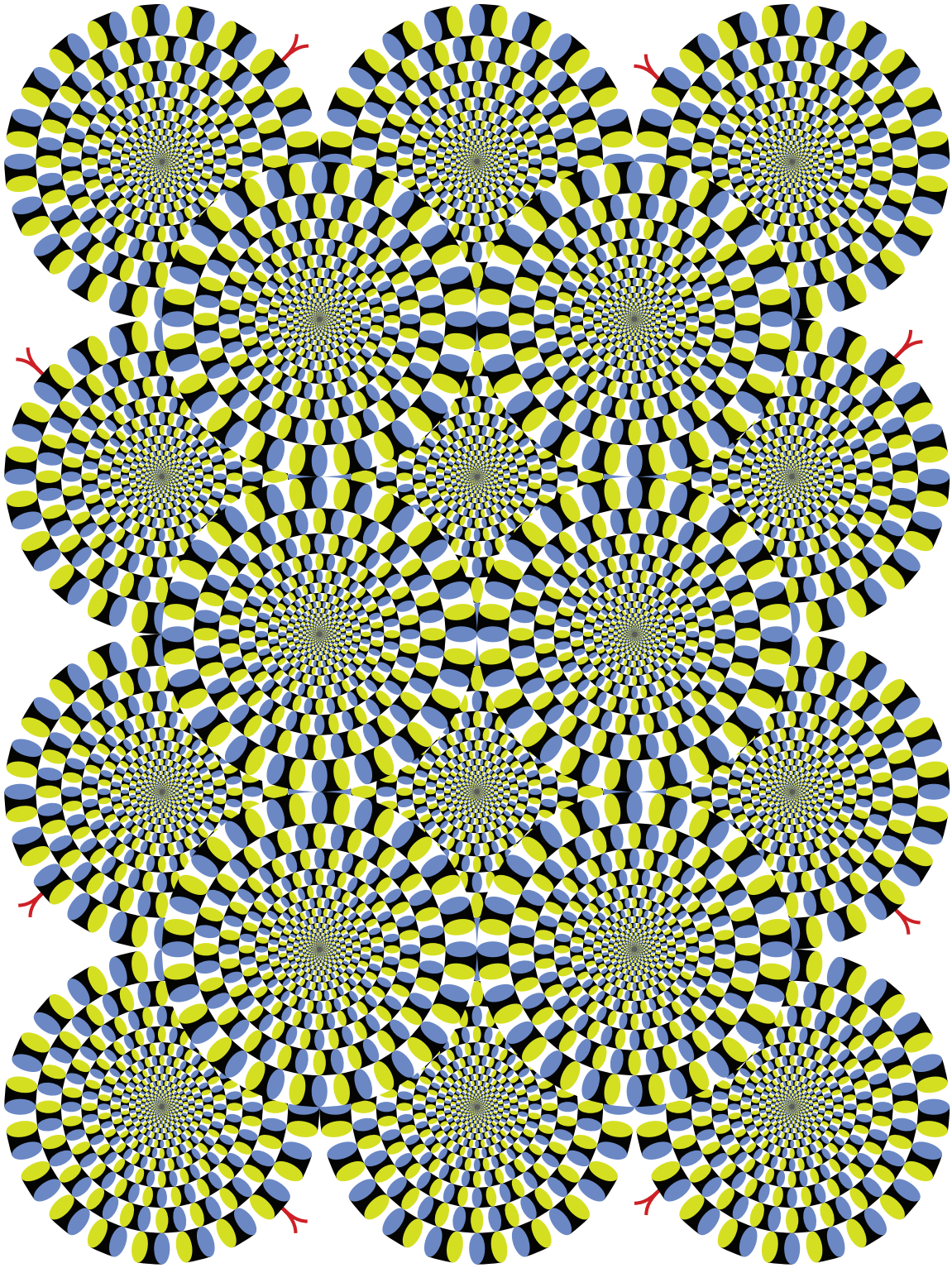


BRIGHTNESS ILLUSIONS

In this illusion, created by vision scientist Edward H. Adelson of the Massachusetts Institute of Technology, squares *a* and *b* are the same shade of gray. (If you don't believe it, cut out the two squares and place them side by side.) This trick of the eye occurs because our brain does not perceive the true colors and brightness of objects in the world but instead compares them with others in their vicinity. For instance, the same gray square will look lighter when surrounded by black than when it is surrounded by white.

Another example: when you read printed text on a page under indoor lighting, the amount of light reflected by the *white* space on the page is lower than the amount of light that would be reflected by the *black* letters in direct sunlight. Your brain doesn't really care about actual light levels, though, and instead interprets the letters as black because they remain darker than the rest of the page, no matter the lighting conditions. In other words, every newspaper is also a visual illusion!

COURTESY OF EDWARD H. ADELSON *M.I.T.*



COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University*

ILLUSORY MOTION

Some stationary patterns generate the illusory perception of motion. This unsettling effect is usually stronger if you move your eyes around the figure. For instance, in this illusion created by Akiyoshi Kitaoka, a professor of psychology at Ritsumeikan University in Japan, the "snakes" appear to rotate. But nothing is really moving other than your eyes!

If you hold your gaze steady on one of the black dots in the center of each "snake," the motion will slow down or even stop. Because holding the eyes still stops the false sense of motion, eye movements must be required to see it. Vision scientists have shown that illusory motion activates brain areas that are similar to those activated by real motion.

3-D ILLUSIONS

Visual artists often try to imitate reality closely. Painters convey the illusion of reality, volume or distance by making intuitive use of perspective, color, lighting and shadow. When they are successful, the artwork is sometimes difficult to distinguish from the subject itself.

Pliny the Elder, in his *Natural History* encyclopedia, narrated the legendary competition between two renowned painters in ancient Greece: Zeuxis and Parrhasius. Each of the artists brought a covered painting to the contest. Zeuxis uncovered his work: he had painted grapes so realistic that birds flew from the sky to peck at them. Convinced of his victory, Zeuxis tried to uncover Parrhasius's painting to confirm the superiority of his work. He was defeated, however, because the curtain he tried to pull back was Parrhasius's painting itself.

Such techniques were carried to the limit in trompe l'oeil, a French term that means "to trick the eye." This style of photographic realism first appeared in the Renaissance and flourished in the 17th century in the Netherlands. The lifelike pictures sometimes appeared to literally jump from the frame. In *The Attributes of the Painter,* a 17th-century work by Cornelius N. Gysbrechts, a painting appears to curl off the artist's easel (*far right*).

The cupola of the St. Ignatius of Loyola church in Rome (*center right*) is a great example of Baroque illusionism. The architect of the church, Orazio Grassi, had originally planned to build a cupola but died before finishing the church, and the money was used for something else. Thirty years later, in 1685, Jesuit artist Andrea Pozzo was asked to paint a fake dome on the ceiling over the altar. Although Pozzo was already considered a master in the art of perspective, the results he accomplished could hardly be believed. Even today many visitors to the church are amazed to find out that the spectacular cupola is not real but an illusion.

Architects soon realized that they could manipulate reality by warping perspective and depth cues to create illusory structures that defied perception. Need a big room in a small space? No problem. Francesco Borromini accomplished just that at the Palazzo Spada, a palace in Rome (*right*). Borromini created this spectacular trompe l'oeil illusion of a 121-foot-long courtyard gallery in a 28-foot-long space. There is even a life-size sculpture at the end of the archway. Not really. The sculpture looks life-size but is actually just two feet tall.

AMBIGUOUS FIGURES

This bunch of violets contains the faces of Napoleon Bonaparte, Marie Louise of Austria and their son. Can you find them among the flowers? Napoleon's admiring troops gave him the name of "*Petit Caporal,*" or "Little Corporal": their leader's short stature had not prevented him from defeating four armies larger than his own during his very first campaign. Years later, when Bonaparte was banished to the isle of Elba, he told his friends he would return with the violets, thus earning the nickname of "Corporal Violet, the little flower that returns with spring." When he broke his imposed exile to return to France, women supporters assembled to sell violets. They would ask passersby, "Do you like violets?" Answering "*oui*" indicated that the person was not a confederate; "*eh bien*" signaled that the respondent adhered to Napoleon's cause. Napoleon's supporters distributed reproductions of this 1815 engraving.

In ambiguous illusions such as this one, the brain interprets the same picture in two different ways, with the two interpretations being mutually exclusive. You can see one of two possible images, but not both at the same time.

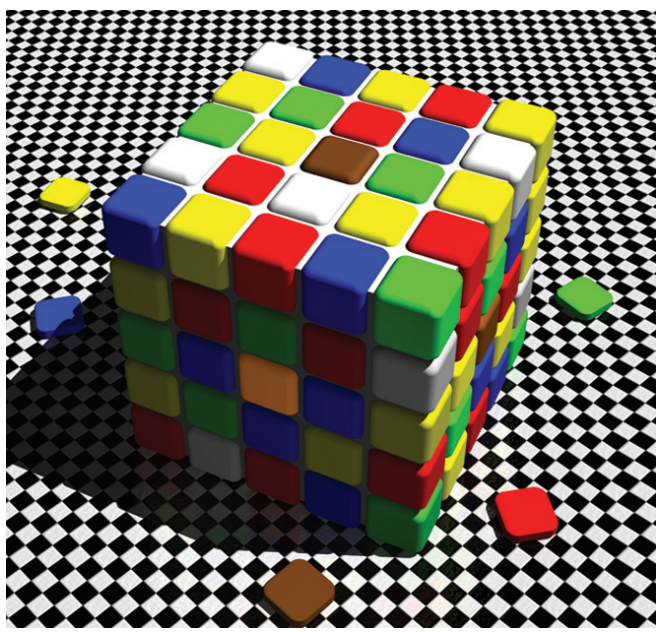
These so-called ambiguous figures are especially powerful tools to dissociate the subjective perception from the physical world. The physical object never changes, yet our perception alternates between two (or more) possible interpretations. For this reason, ambiguous illusions are used by many laboratories in the search for the neural correlates of consciousness.

ANDREA JEMOLO *Corbis (top)*; © THE TRUSTEES OF THE BRITISH MUSEUM (*bottom*)

COURTESY OF DARRIENNE THOBAVEN (*top left*); RMN-GRAND PALAIS/ART RESOURCE, NY (*top right*); COURTESY OF R. BEAU LOTTO *University College London* AND DALE PURVES *Duke University* (*bottom*)

COLOR IN CONTEXT

This image, created by R. Beau Lotto of University College London with Dale Purves of Duke University, is another example of how the brain can perceive the same color differently when viewed in a different context. The central brown square on the top of the cube is exactly the same color as the central orange square on the side of the cube facing the viewer. The latter square looks orange because the lighting and surrounding squares make it appear brighter than the brown square in the mind's eye.



A Perspective ON 3-D VISUAL ILLUSIONS

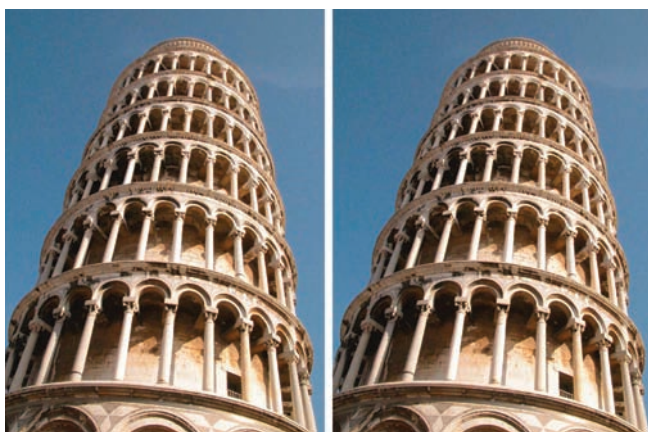
By Stephen L. Macknik and Susana Martinez-Conde

What the leaning tower and related illusions reveal about how your brain constructs 3-D images

How could we have missed it? Hundreds, perhaps *thousands*, of visual scientists, psychologists, neuroscientists, visual artists, architects, engineers and biologists all missed it—until six years ago. The "it" in question is the leaning tower illusion, discovered by Frederick Kingdom, Ali Yoonessi and Elena Gheorghiu, all then at McGill University. In this illusion, two identical side-by-side images of the same tilted and receding object appear to be leaning at two different angles. This incredible effect was first noticed in images of the famed Leaning Tower of Pisa, but it also works with paired images of other receding objects.

The leaning tower illusion is one of the simplest visual tricks one can produce, but it is also one of the most profound in relation to our understanding of depth perception. This fact is why vision scientists are shaking their heads in disbelief that they did not notice the illusion earlier. Kingdom and his colleagues announced the illusion at the 2007 Best Illusion of the Year Contest, where it won first prize.

The annual contest, which we organize and which is hosted by the Neural Correlate Society, celebrates the ingenuity and creativity of the world's premier creators of visual illusions, both artists and scientists. Contestants submit novel visual illusions (that is, unpublished or published no earlier than the previous year). An international panel of impartial judges conducts the initial review and narrows the dozens of submissions down to the 10 best entries. The top 10 creators then compete in Naples, Fla., during a gala celebration, in which the audience chooses the top three winners. First, second and third prizes take home the coveted "Guido" (a three-dimensional illusion sculpture created by renowned Italian sculptor Guido Moretti).



FROM "THE LEANING TOWER ILLUSION: A NEW ILLUSION OF PERSPECTIVE," BY F.A.A. KINGDOM, A. YOONESSI AND E. GHEORGHIU, IN *PERCEPTION*, VOL. 36, NO. 3; 2007. REPRINTED WITH PERMISSION FROM PION LTD, LONDON (WWW.ENVPLAN.COM)

TWIN TOWERS?

In the leaning tower illusion, the tower on the right appears to be leaning more than the tower on the left. Yet these two photographs of the Leaning Tower of Pisa are duplicates.

The illusion reveals the way in which the human visual system uses perspective to help construct our perception of 3-D objects. We say "construct" because the visual system has no direct access to 3-D information about the world. Our perception of depth results from neural calculations based on a set of rules.

These rules include the following: perspective (parallel lines appear to converge in the distance); stereopsis (our left and right eyes receive horizontally displaced images of the same object, resulting in the perception of depth); occlusion (objects near us occlude objects farther away); chiaroscuro (the contrast of an object as a function of the position of the light source); and sfumato (the feeling of depth that one gets from the interplay of in- and out-of-focus elements in an image, as well as from the level of transparency of the atmosphere itself). Because the towers pictured in these paired images do not converge as they recede, the brain mistakenly perceives them as nonparallel and diverging.

To learn more about this illusion, go to http://illusionoftheyear.com/2007/the-leaning-tower-illusion

COMING TOGETHER

The leaning tower illusion shows that the brain uses the convergence angle of two objects as they recede into the distance to calculate the relative angle between them. When two parallel towers appear in the same photograph, such as the Petronas Twin Towers in Kuala Lumpur, we perceive them as parallel because they appear to converge in the distance as they recede.

BREAKING THE RULES

Further analysis of similar images reveals subtleties in the way our visual system processes the perception of depth and perspective. For instance, the leaning tower illusion also works with paired images of train tracks, challenging the classical rules of perspective. It is hard to believe, but these are actually identical images of parallel train tracks. Although the angles are the same in both images, the brain perceives them as being quite different.

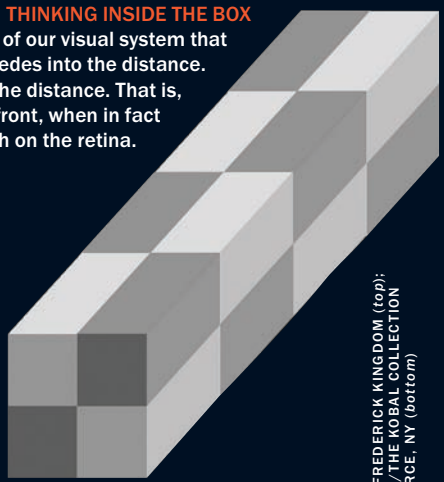
LACKING DEPTH

The leaning tower illusion does not occur when viewing two leaning Japanese *manga* girls, even though the two cartoon images are tilted. The reason is that the cartoon girls do not appear to recede in depth, so our brain does not expect that they would converge in the distance. This phenomenon demonstrates that the brain applies its depth-perception tool kit only in specific situations.

THOMAS HALTNER (*top*); COURTESY OF BRIAN MICKLETHWAIT (*middle*); COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University* (*bottom*)

THINKING INSIDE THE BOX

The leaning tower illusion is such a fundamental feature of our visual system that it works even if one draws a 3-D solid object as it recedes into the distance. The parallel lines give the illusion of diverging in the distance. That is, the box appears wider at the back than it does at the front, when in fact the back and front are precisely the same width on the retina.



COURTESY OF FREDERICK KINGDOM (*top*); WARNER BROS./THE KOBAL COLLECTION AT ART RESOURCE, NY (*bottom*)

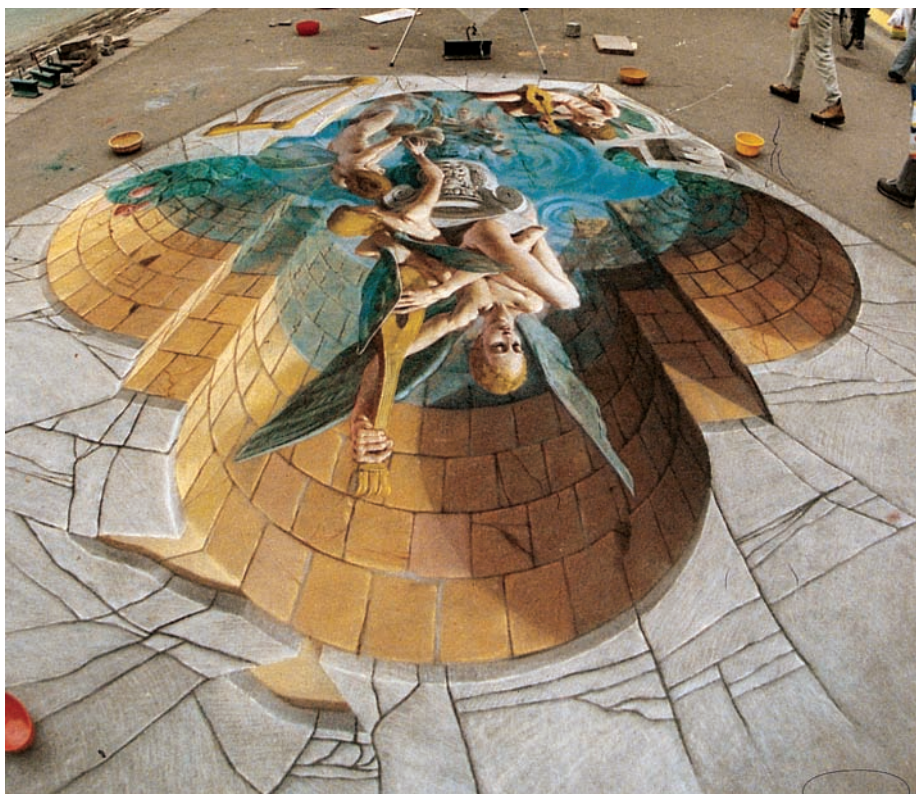
WHAT IS REAL?

Just as the painter creates the illusion of depth on a flat canvas, our brain creates the illusion of depth based on information arriving from our essentially 2-D retinas. Visual illusions show us that depth, color, brightness and shape are not absolute terms but are subjective, relative experiences actively created by complicated brain circuits. This is true not only of visual experiences but of any sensation. Whether we experience the feeling of "redness," the appearance of "squareness," or emotions such as love and hate, these are the results of the electrical activity of neurons in our brain.

In the movie *The Matrix,* Morpheus asks Neo: "What is real? How do you define real? If you're talking about what you can feel, what you can smell, what you can taste and see, then real is simply electrical signals interpreted by your brain." What the movie doesn't tell us is that even when Neo awakens from the fake world of the "matrix" into the "real world," his brain will continue to construct his subjective experience, as all our brains do, and this experience may or may not match reality. So in a way, we all live in the illusory matrix created by our brain.

ANAMORPHIC ART

Thanks to the brain's rules of perspective, artists can fool us into perceiving two-dimensional drawings as three-dimensional. Artist Kurt Wenner's 3-D pavement paintings—such as *Muses* in Lucerne, Switzerland—are anamorphic illusions that create an impression of three dimensions when seen from one particular viewpoint (*above*). From the "wrong" side, however, you can see the distortions that Wenner uses to create the 3-D effect (*right*). The word "anamorphic" comes from the Greek, meaning "formed again."



KURT WENNER

ALL Deceptions GREAT AND SMALL

By Susana Martinez-Conde and Stephen L. Macknik

Does size matter? To your brain, it doesn't

Size matters not. Look at me. Judge me by my size, do you?
—Yoda, Jedi master

AS BOTH the midget in the country of Brobdingnag and the giant on the island of Lilliput, Lemuel Gulliver—the protagonist of Jonathan Swift's *Gulliver's Travels*—experienced firsthand that size is relative. As we cast a neuroscientific light on this classic book, it seems clear to us that Swift, a satirist, essayist and poet, knew a few things about the mind, too. Absolute size is meaningless to our brain: we gauge size by context. The same medium-sized circle will appear smaller when surrounded by large circles and bigger when surrounded by tiny ones, a phenomenon discovered by German psychologist Hermann Ebbinghaus. Social and psychological context also causes us to misperceive size. Recent research shows that spiders appear larger to people who suffer from arachnophobia than to those who are unafraid of bugs and that men holding weapons seem taller and stronger than men who are holding tools. In this article, we present a collection of illusions that will expand your horizons and shrink your confidence in what is real. Try them out for size!

BEAT GLANZMANN *Corbis*

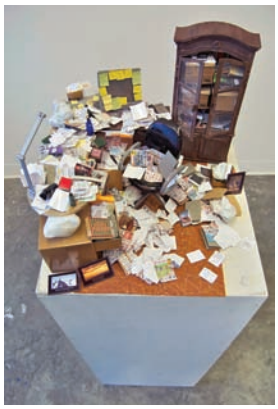
FULL MOON

The full moon rising on the horizon appears to be massive. Hours later, when the moon is high overhead, it looks much smaller. Yet the disk that falls on your retina is not smaller for the overhead moon than it is for the rising moon. So why does the overhead moon seem smaller? One answer is that your brain infers the larger size of the rising moon because you see it next to trees, hills or other objects on the horizon. Your brain enlarges the moon to fit the context. Look for this effect the next time you see the moon in real life.

SMALL CHANGE

Do you see tiny objects photographed with a macro lens? Look again. This remarkable illusion combines tilt-shift photography—in which the photographer uses selective focus and a special lens or tilted-shot angle to make regular objects look toy-size—with the strategic placement of a giant coin. Art designers Theo Tveterås and Lars Marcus Vedeler, from the Skrekkøgle group, created the enormous 50-cent euro coin from painted and lacquered wood at a 20:1 scale.

COURTESY OF THEO TVETERÅS AND LARS MARCUS VEDELER

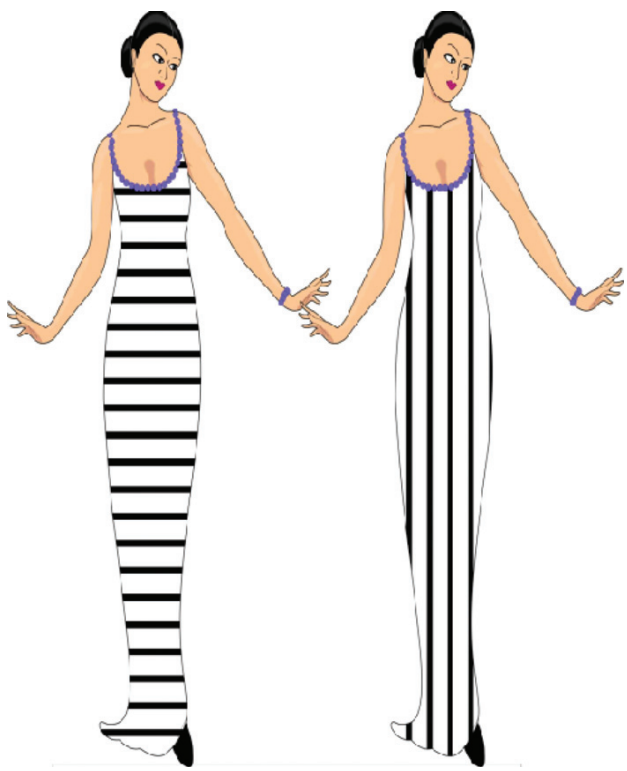


BARBIE TRASHES HER DREAMHOUSE

At first sight, they look like real-life scenes from the television show *Hoarders,* precleanup. In reality, they are photographs of 1:6 scale dioramas by St. Louis–born artist Carrie M. Becker. She makes the cardboard boxes, garbage bags and other trash herself. The furniture and tiny objects are from Barbie's Dreamhouse and a Japanese miniatures company called Re-Ment. Becker filths up the rooms with actual dirt collected from the filter of a DustBuster, using the occasional Re-Ment meatball to simulate dog poop on the floor. When she photographs the scenes without an external reference, our brain relies on our everyday experience and assumes that the minuscule objects are life-size. Only in proximity to an extraneous, actual-size object does the illusion fail.

SUPERSIZE ME

You can look 10 pounds thinner with a well-known slimming trick: vertical lines elongate your shape and give you a more svelte appearance, right? Wrong! Vision scientists Peter Thompson and Kyriaki Mikellidou of the University of York in England say instead that it is time to ditch your vertical-striped wardrobe and invest in some horizontal-striped outfits. They found that vertical stripes on clothing make the wearer appear fatter and shorter than horizontal stripes do. Notice that the vertical-striped lady seems to have wider hips than the horizontal-striped model in the accompanying cartoons. The phenomenon is based on the Helmholtz illusion, in which a square made up of horizontal lines appears to be taller and narrower than an identical square made of vertical lines. The original report from 1867 of this illusion contained the intriguing reflection that ladies' frocks with horizontal stripes make the figure look taller. Because the remark ran counter to contemporary popular belief, the York researchers decided to put it to the test, finding that 19th-century German physicist and physician Hermann von Helmholtz did indeed have a great eye for fashion.



COURTESY OF CARRIE M. BECKER (*top*); FROM "APPLYING THE HELMHOLTZ ILLUSION TO FASHION: HORIZONTAL STRIPES WON'T MAKE YOU LOOK FATTER," BY PETER THOMPSON AND KYRIAKI MIKELLIDOU, IN *I-PERCEPTION*, VOL. 2, NO. 1; 2011. USED WITH PERMISSION FROM PION LTD, LONDON (WWW.PION.CO.UK) (*bottom*)

BLOWN AWAY

Objects project smaller images on our retinas as they move away from us, which can make it hard to decide if an item is truly small or just far away (as we see in this photograph). Forced perspective photography uses this ambiguity to great effect, while eliminating many of the habitual strategies that our brain uses to distinguish size from distance, such as stereopsis (our visual system can calculate the depth in a scene from the slight differences between our left and right retinal images) and motion parallax (as we move, objects closer to us move farther across our field of view than distant objects do).

COURTESY OF JEPPE OLSEN (*top*); ANTHONY ROSENBERG *iStockphoto (bottom)*

TALL AND VENTI

Is your cuppa joe half empty or half full? It depends on your outlook—and on a little twist on the Jastrow illusion, named after Polish-born American psychologist Joseph Jastrow. In this classic illusion, two identical arches positioned in a certain configuration appear to have very different lengths. Magician Greg Wilson and writer and producer David Gripenwaldt realized that Starbucks coffee sleeves have the perfect shape for an impromptu demonstration of the Jastrow illusion, so now you can amaze your office mates at your next coffee break.

All you need to do is align the coffee sleeves as in the accompanying photograph and—presto!—your tall cup sleeve is now venti-size! Your brain compares the upper arch's lower right corner with the lower arch's upper right corner and concludes, incorrectly, that the upper sleeve is shorter than the lower sleeve. (We would like to thank magician Victoria Skye for her demonstration of the Jastrow illusion with Starbucks coffee sleeves.)

(Further Reading)

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A Faithful RESEMBLANCE

By Susana Martinez-Conde and Stephen L. Macknik

When seeing is believing

There are things in that [wall]paper that nobody knows but me, or ever will. Behind that outside pattern the dim shapes get clearer every day. It is always the same shape, only very numerous. And it is like a woman stooping down and creeping about behind that pattern.

—Charlotte Perkins Gilman,
"The Yellow Wallpaper," 1892

THE PROTAGONIST in Charlotte Perkins Gilman's short story "The Yellow Wallpaper" suffers from the most notable case of pareidolia in fiction. Pareidolia, the misperception of an accidental or vague stimulus as distinct and meaningful, explains many supposedly paranormal and mystical phenomena, including UFO and Bigfoot sightings and other visions. In Gilman's story, the heroine, secluded in her hideously wallpapered bedroom and having nothing with which to occupy herself, is driven to insanity—full-blown paranoid schizophrenia—by the woman behind the yellow pattern. As she descends into madness, she comes to believe that she is imprisoned by the wallpaper.

Mental disease can aggravate pareidolia, as can fatigue and sleepiness. After a recent surgery, one of us (Martinez-Conde) noticed faces everywhere, in places as unlikely as the ultrasound images of her left arm during an examination of potential postsurgical blood clots. She realized at once that the ubiquitous faces were the product of lack of sleep and the high titer of pain medication in her bloodstream, so she was more fascinated than concerned. Her doctor agreed but made a note in her file for a different drug regime in the future. Just in case. Luckily, the hospital room's walls were bare, and there was no yellow wallpaper in sight. Our brain is wired to find meaning. Our aptitude to identify structure and order around us, combined with our superior talent for face detection, can lead to spectacular cases of pareidolia, with significant effects in society and in culture.

GOD SAVE THE QUEEN
Canadian banknotes issued in 1954 featured a portrait of British monarch Elizabeth II. The young queen looked majestic and serene, despite the grinning demon tucked in the curls behind her regal ear (colored red, to make it easier to see). Talk about having a royally bad hair day! Canadians were understandably appalled by what became known as the "Devil's head" or "Devil's face" series. In 1956 the Bank of Canada ordered banknote companies to darken the highlights in the queen's hair, effectively exorcising the King of Hell from Canadian currency.

COURTESY OF NATIONAL CURRENCY COLLECTION/CURRENCY MUSEUM/BANK OF CANADA, OTTAWA

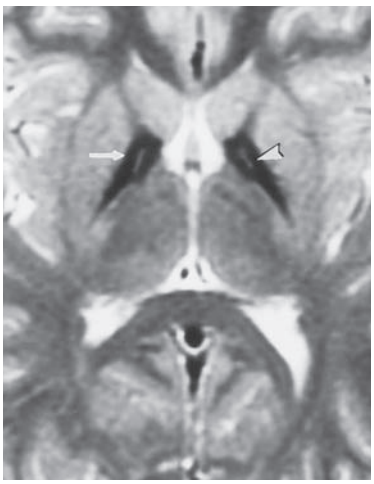
COURTESY OF NASA

THE FACE FROM SPACE

In 1976, as NASA's Viking 1 circled Mars looking for possible landing sites for its sister ship Viking 2, it spotted the likeness of a mile-wide human (or maybe Martian?) face, staring back from the Red Planet's region of Cydonia. Scientists believed that the Martian "sphinx" was one of numerous mesas around Cydonia and that unusual shadows made it look like a humongous head. Conspiracy theorists favored the alternative explanation of a government cover-up, however, and criticized NASA's unsuccessful attempts to hide the remnants of an ancient Martian civilization. Some two decades later, obtaining high-resolution images of Cydonia became a priority for NASA. "We felt this was important to taxpayers," said Jim Garvin, then chief scientist for NASA's Mars Exploration Program. "We photographed the Face as soon as we could get a good shot at it." In April 1998 the Mars Orbiter Camera team snapped a picture 10 times sharper than the original Viking photos, revealing the mystifying Face on Mars to be . . . a mesa.

EYE OF THE TIGER

Neurologists Péricles Maranhão-Filho and Maurice B. Vincent of the Federal University of Rio de Janeiro advocate the use of face-detection illusions as heuristics to help doctors diagnose neurological diseases. One is PKAN, or pantothenate kinase–associated neurodegenerative disease, which results from mutations in the genes encoding the enzyme responsible for the biosynthesis of coenzyme A. Typically PKAN starts during childhood, and most patients lose the ability to walk within 15 years. The brains of PKAN patients show decreased intensity of the globus pallidus (involved in motor control) from iron accumulation, with a central area of increased intensity from necrosis. The image looks decidedly feline, providing the so-called eye-of-the-tiger sign.

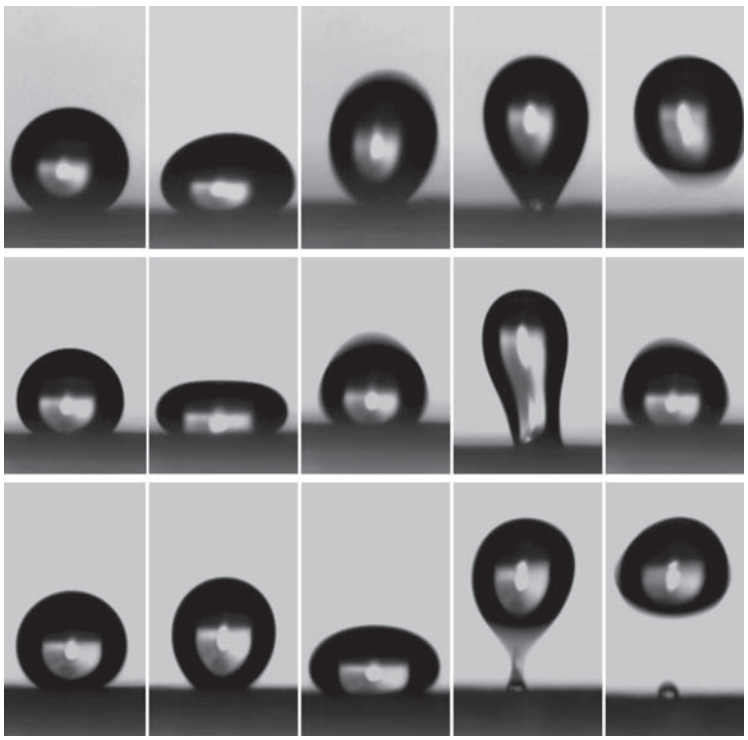


SATAN IN THE SMOKE

Photojournalist Mark D. Phillips captured the World Trade Center, engulfed in smoke and flames, seconds after the second plane attack on 9/11. Unknown to Phillips at the time, the picture, distributed by Associated Press and published on the front pages of several newspapers, contained the face of none other than the Prince of Darkness. A media frenzy ensued, and Phillips, who retired from photojournalism that same day, received more than 30,000 messages related to the "face of evil" in the murky cloud and the feelings it brought forth in the viewers.

One year later computer scientists Vladik Kreinovich and Dima Iourinski, both then at the University of Texas at El Paso, published a geometric analysis of the face in the photograph, also seen in a different image from CNN. The analysis showed that perturbations in the smoke can consist of horizontal lines (such as the "eyes" and "mouth") and vertical lines (such as the "nose") overlaid on a conic surface (the "head"). The scientists concluded that both the background shape (the cone) and the features on the background (horizontal and vertical lines) are naturally explained by the physics and geometry of smoke plumes emanating from fire.

FROM "THE EYE-OF-THE-TIGER SIGN," BY R. PAUL GUILLERMAN, IN *RADIOLOGY*, VOL. 217; DECEMBER 2000. USED WITH PERMISSION
FROM RADIOLOGICAL SOCIETY OF NORTH AMERICA *(top left)*; ANDY GEHRIG *iStockphoto (top right)*; MARK D. PHILLIPS *markdphillips.com (bottom)*



FROM "THE FACE OF TESTICULAR PAIN: A SURPRISING ULTRASOUND FINDING," BY G. GREGORY ROBERTS AND NAJI J. TOUMA, IN *UROLOGY* VOL. 78, NO. 3; SEPTEMBER 2011. REPRINTED WITH PERMISSION FROM ELSEVIER *(top)*; COURTESY OF JONATHAN B. BOREYKO AND CHUAN-HUA CHEN *Duke University (middle)*; © SALVADOR DALÍ, FUNDACIÓ GALA-SALVADOR DALÍ, ARTISTS RIGHTS SOCIETY, NEW YORK, 2013 *(bottom)*

WHERE YOU LEAST EXPECT IT

Medical imaging is a new fertile ground for pareidolia. Urologists G. Gregory Roberts and Naji J. Touma of Queen's University in Ontario were shocked to discover a face, contorted in agony, in the scrotal ultrasound images (*top*) of a 45-year-old man afflicted with severe testicular pain. The doctors toyed with the idea that the image might be a manifestation of Min, the Egyptian god of male virility, but ultimately deemed the facial features in the benign mass accidental.

***Physics World* reporter James Dacey was similarly startled to discover the face of Beatle Ringo Starr in a series of high-speed images of waterdrops bouncing on the surface of a lotus leaf, captured by a team of researchers at Duke University (*middle*).**

The brain's capacity to establish false links among things that are not actually connected is essential to the "paranoiac-critical method" artistic technique invented by Spanish surrealistic painter Salvador Dalí. (Paranoia and pareidolia have the same etymology, from the Greek *para-* for "instead of" and *-oid, -oeides* or *-eidos* for "form.") In Dalí's *Slave Market with the Disappearing Bust of Voltaire,* several features in Voltaire's face are formed by the bodies of people in the scene (*bottom*).

Dartmouth College neuroscientist Ming Meng and his colleagues have imaged the brains of observers while they viewed faces and objects that looked like faces. The left fusiform gyrus was activated by both faces and objects resembling them, whereas the right fusiform gyrus showed much stronger activation to actual faces than to look-alikes.

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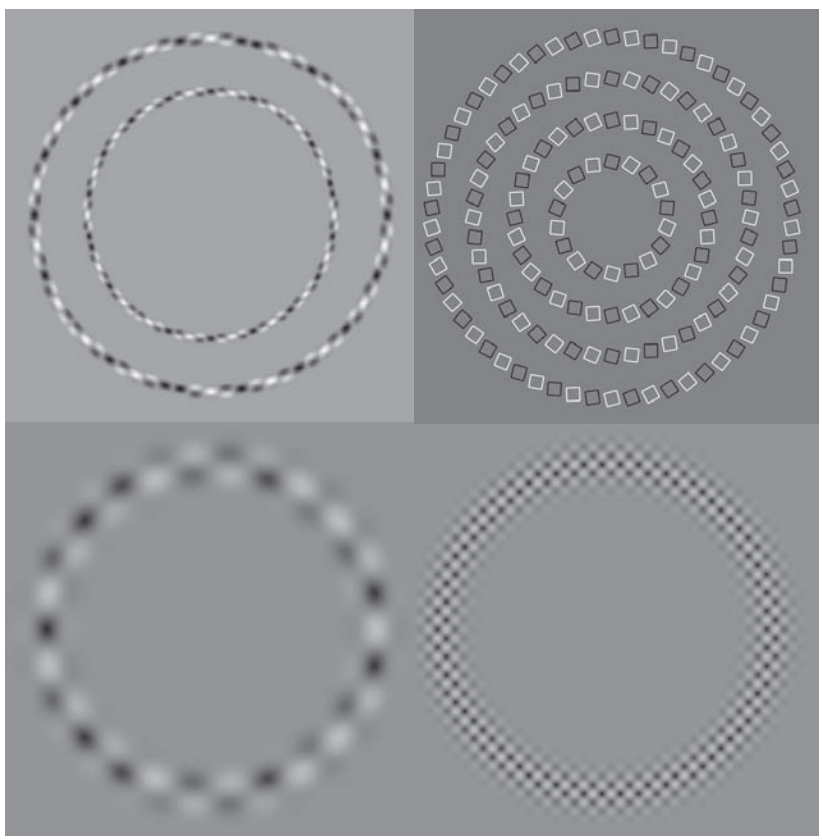
Your Twisted

LITTLE MIND

By Stephen L. Macknik and Susana Martinez-Conde

Illusions that distort your perception

VISUAL PERCEPTION begins with our retinas locating the edges of objects in the world. Downstream neural mechanisms analyze those borders and use that information to fill in the insides of objects, constructing our perception of surfaces. What happens when those borders—the fundamental fabric of our visual reality—are tweaked? Our internal representation of objects fails, and our brain's ability to accurately represent reality no longer functions. Seemingly small mistakes lead to the very distorted perceptions of an illusory world.



COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University (top row, left)*; COURTESY OF BAINGIO PINNA *University of Sassari (top row, right)*; COURTESY OF DAVID WHITAKER *University of Bradford (bottom row)*

CIRCULAR REASONING

The upper left pair of nested circular twisted cords shows how a subtle local effect can have major global consequences on our perception of shapes, even one as deceivingly simple as a circle. (To convince yourself that these circles do not actually have corners, see the video at www.youtube.com/watch?v=aXndBs0dvdg&feature=plcp.) The twist in the cords even works when the twisted elements are not touching, as in the spectacular *Intertwining Illusion* by vision scientist Baingio Pinna of the University of Sassari in Italy (*top right*). Because the interacting visual elements are not in contact with one another, Pinna's version is strongest when you see it with your peripheral vision—out of the corner of your eye. Visual neurons processing peripheral information have low spatial resolution, allowing them to "see" the gross details of objects only, so even distant tilted squares produce the perception of a twisted cord. The low resolution of peripheral visual neurons also plays a role in the bizarre *It's a Circle, Honest!* illusion by vision scientist David Whitaker of the University of Bradford in England and a top-10 finalist in the 2007 Best Illusion of the Year Contest (http://illusionoftheyear.com).

On the lower left, the circle looks round only if you look directly at it; if you position it in the corner of your eye, it has corners! The smaller elements making up the lower right circle smear out to gray in the visual periphery, making the circle look more rounded.

PETER BENNETTS (*top*); SCIENTIFIC AMERICAN MIND (*bottom*)

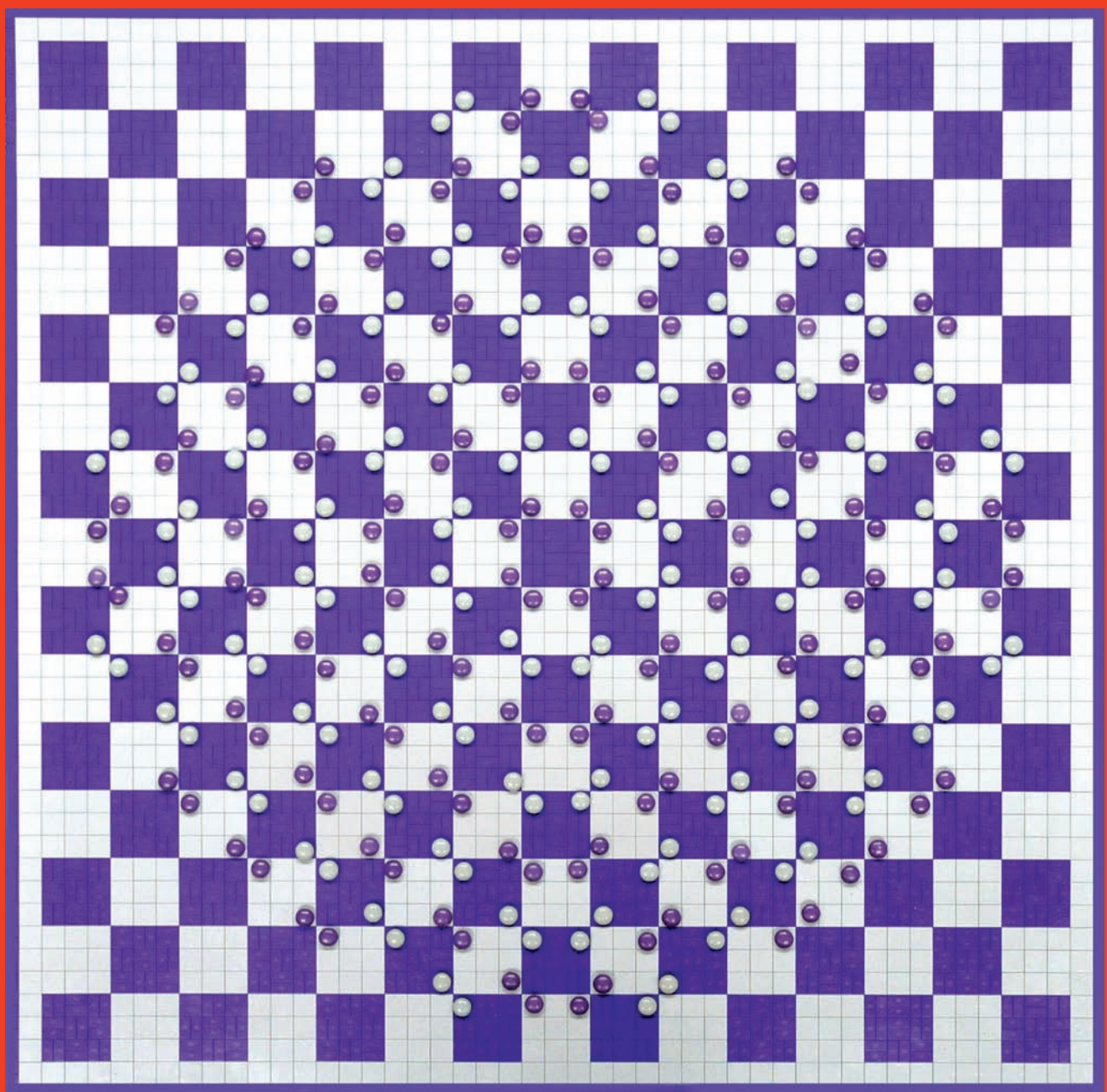
PLUMB CRAZY

No, the architects of this building were not drunk at the drawing board. In fact, the structure is perfectly rectilinear in every way. No slants, no tilts and no curves: just good old traditional 90-degree angles at work here. The Australian architectural firm of Ashton, Raggatt, and McDougall based the façade design at the Port 1010 building in Melbourne on a famous bit of visual trickery known as the café wall illusion, popularized by the late vision scientist Richard Gregory of the University of Bristol in England. Mark McCourt, a vision scientist at North Dakota State University, has shown that the positions of the black-and-white bricks invoke a reverse contrast effect called brightness induction, which results in the mortar having the appearance of a twisted cord. Vision scientist and illusion creator Akiyoshi Kitaoka of Ritsumeikan University in Japan has further demonstrated this effect in minimalist fashion by isolating it to a single row of mortar with blocks. The alternation of black-and-white brick positions results in an alternating direction in the twisted cords of the mortar. The brain interprets these cords as being slightly tilted depending on the direction of the twist.

BUILDING THE IMPOSSIBLE, ONE LEGO AT A TIME

Don't believe any of this so far? Think it's all a bunch of camera tricks? Well, you don't have to take our word for it. Go to a Lego store and buy a baseplate that is at least 43 × 43 studs in size, 946 one-by-two tiles (554 black and 392 white), 196 one-by-one tiles (half black, half white), and 240 individual studs (half black, half white). You can then make your own Lego version of *A Bulge,* by Kitaoka. The version below uses purple and white Legos, with M&Ms instead of studs.

To see the illusion disappear with a single breath, watch this video at www.youtube.com/watch?v=QKCSBkdEUXQ

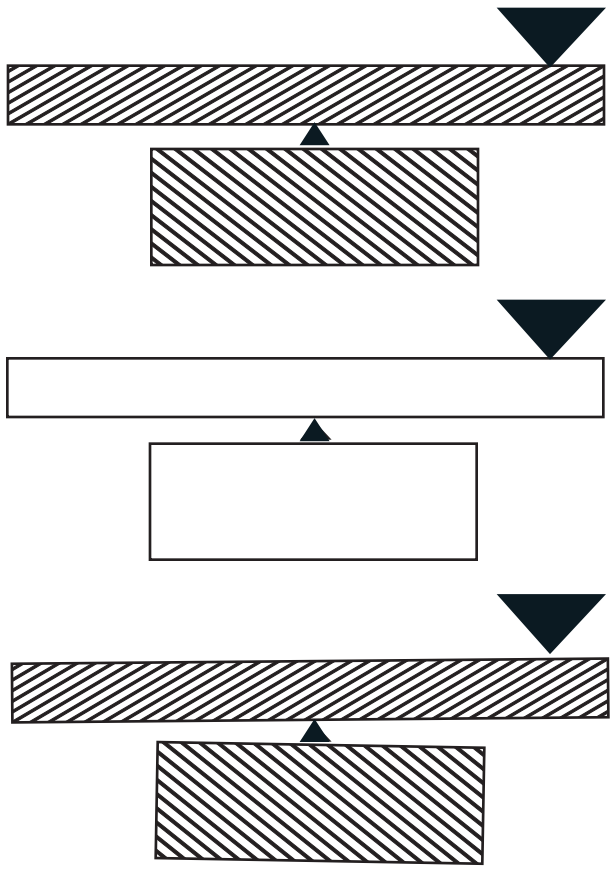


ADAPTED FROM *A BULGE,* BY AKIYOSHI KITAOKA; COURTESY OF MARY COFFELT, BRIENA HELLER AND MICHAEL McCAMY

PASCAL LE SEGRETAIN *Getty Images (left);* SCIENTIFIC AMERICAN MIND *(right)*

TWISTED SISTER

Women's makeup enhances the attractive facial features while hiding the undesirable. Now there is an outfit to accomplish the same illusory feat for your body. Actor Kate Winslet's dress, created by British fashion designer Stella McCartney, uses contrasting shapes to accentuate hips, shoulders and otherwise highlight the female form. For maximum effectiveness, be sure to wear it only in front of a black background.



TEETER-TOTTER SEESAW

Spatial distortions can be measured for their power to alter perception. The seesaw at the top seems to tilt to the right, although, in fact, it is not tilting at all. If we remove the twisting candy-cane stripes from within, we now see the veridical planks and their untilted truth. A clever variant of this illusion, with a physically tilted plank that appears level through illusory means, reveals that the illusion is equivalent, perceptually, to as much as a four-degree actual tilt.

A nice animated version of the effect is at www.moillusions.com/2009/02/slanted-seesaw-optical-illusion.html

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Vanished WITHOUT A TRACE

By Susana Martinez-Conde and Stephen L. Macknik

Fading illusions play hide-and-seek with your perception

I don't think there is anything wrong with white space. I don't think it's a problem to have a blank wall.

—Annie Leibovitz

ACCORDING TO a legend that one of us (Martinez-Conde) heard growing up in Spain, anybody can see the Devil's face. All you need to do is to stare at your own face in the mirror at the stroke of midnight, call the Devil's name and the Prince of Darkness will look back at you. Needless to say, I was both fascinated and terrified by the possibility. And I knew this was an experiment I must try. I waited a day or two to gather my courage, then stayed awake until midnight, got up from my bed,

ART WOLFE/WWW.ARTWOLFE.COM

VANISHING ACT

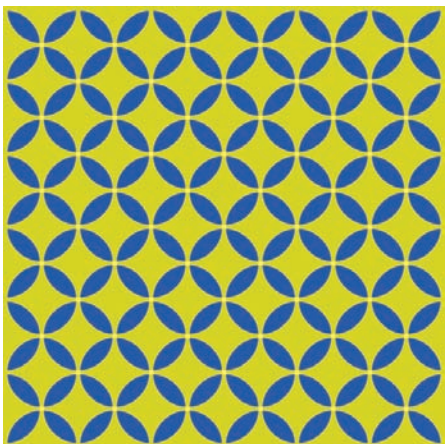
Camouflage and the perceptual effect known as Troxler fading combine to make a leopard nearly invisible. Look around the image. Hint: The leopard's head is hiding in the tall grass near the lower right corner. Once you find it, hold your gaze on the tree trunk while paying attention to the animal's location. He's gone! Look straight at the leopard to revive your perception.

and into the bathroom I went. I closed the door behind me so that my family would not hear me calling out loud for Satan, faced my wide-eyed reflection, made my invocation, and then … nothing happened. I was disenchanted (literally) but also quite relieved.

Now, three decades later, a paper entitled "Strange-Face-in-the-Mirror Illusion," by vision scientist Giovanni B. Caputo of the University of Urbino in Italy, may explain my lack of results. Caputo asked 50 subjects to gaze at their reflected faces in a mirror for a 10-minute session. After less than a minute, most observers began to perceive the "strange-face illusion." The participants' descriptions included huge deformations of their own faces; seeing the faces of alive or deceased parents; archetypal faces such as an old woman, child or the portrait of an ancestor; animal faces such as a cat, pig or lion; and even fantastical and monstrous beings. All 50 participants reported feelings of "otherness" when confronted with a face that seemed suddenly unfamiliar. Some felt powerful emotions.

After reading Caputo's article, I had to give "Satan" another try. I suspected that my failure to see anything other than my petrified self in the mirror 30 years ago had to do with suboptimal lighting conditions for the strange-face illusion to take place. Caputo recommended dim lighting, so that observers might see their facial features in detail but experience attenuated color perception. So this time I turned off the bathroom lights and turned on my cell phone's flashlight, then placed it on the floor behind me, so that I could not see its reflection on the mirror. Then I looked at myself and waited.

My efforts were rewarded quickly. Portions of my face started to disappear, contract or expand, and suddenly all the features would come back, giving me a bit of a start. I was particularly thrilled to experience some of the dissociative identity effect that the experimental participants reported, feeling as if the face staring back at me



HOW MANY DOTS?

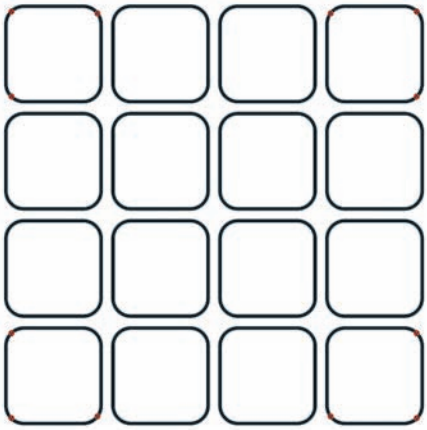
This pattern, generated by vision scientist Akiyoshi Kitaoka of Ritsumeikan University in Japan, contains a yellow dot at the center of each set of four blue "petals." That makes a total of 61 yellow dots! To prove it to yesself, examine each "flower" in turn and see that all of them contain a central yellow spot. The problem is that you can see only one spot at a time. The others disappear when you are not looking at them directly.

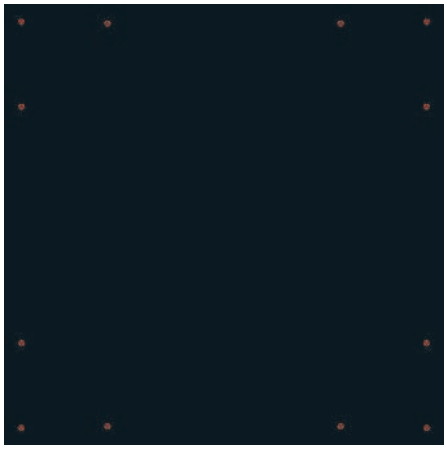
A FADING IMPRESSION

***Impression, Sunrise,* by French painter Claude Monet in 1872, gave its name to the Impressionist movement. The subject of the painting is the harbor of Le Havre in France, as seen from Monet's window. It was not, however, Monet's actual view of the scene, as he later explained, but his "impression"—hence the title. Indeed, *Sunrise* does not accurately represent reality: the rising sun appears much brighter than the surrounding sky, as it should in real life, but that perception is an illusion. Monet used pigments of matching luminance, or brightness, but different chromatic content, or hues, to represent the sun and the sky. Harvard University neurobiologist Margaret S. Livingstone has proposed that this equiluminant quality, where objects in the image have the same luminance as the background, is what gives the sun its eerie, almost pulsating, lifelike appearance. A black-and-white reproduction reveals that the sun has the same physical luminance as the background clouds.**

Equiluminant objects are somewhat difficult to see, which makes them more susceptible to Troxler fading. Neuro-ophthalmologists Avinoam B. Safran and Theodor Landis, both then at University Hospitals of Geneva, noticed that if you fix your gaze on the image of the sailor in Monet's painting for several seconds, while paying attention to the sun, the solar disk will disappear progressively, being replaced by the surrounding sky.

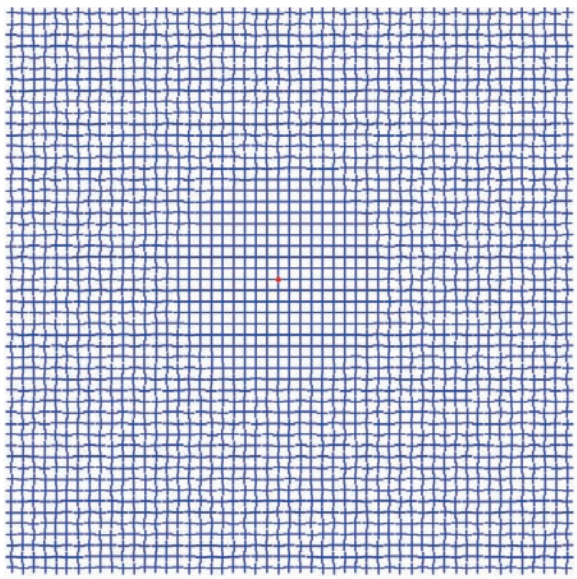
COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University (top);* ERICH LESSING/ART RESOURCE, NY *(bottom)*





LURKING LADYBUGS
In the left image of the pair that makes up this illusion, also by Kitaoka, each of the four squares in the corners has three ladybugs. The little insects are easy to see as you look around the image, but when you stare at the center of the pattern they vanish immediately. The right-hand image shows they do not become invisible by virtue of their small size: in the absence of the squares, all 12 ladybugs are perceptually prominent, no matter where in the image you look.

HEALING GRID
This illusion, created by cognitive neuroscientist Ryota Kanai, then at Utrecht University in the Netherlands, was a top-10 finalist in the 2005 Best Illusion of the Year Contest (http://illusionoftheyear.com). Explore the image freely, and you will see a regular pattern of intersecting horizontal and vertical lines in the center, surrounded by an irregular grid of misaligned crosses. Choose one of the intersections on the center of the image and stare at it for 30 seconds or so. You will see that the grid "heals" itself, becoming perfectly regular all the way through. The illusion results from both perceptual fading and the ensuing neural guesstimates that our brain imposes to "fill in" the outer parts of the image based on the available information from the center, in addition to our nervous system's intrinsic tendency to seek structure and order, even when the sensory input is fundamentally disorganized.



was both mine and yet not mine. Disappointingly, I did not see any monstrous creatures or ghosts of ancestors calling me from the beyond (or even Satan, for that matter), but I think I came close to seeing one of the "archetypal" faces. Weirdly, halfway through the experiment, my face appeared to morph into a sepia portrait of an old Native American warrior. But as soon as it arrived, it was gone.

Fade to Gray

Why does this happen? To explain, we need to start with Erasmus Darwin, the English natural philosopher and physician and grandfather of Charles Darwin. In the late 18th century he described how objects can fade after steady gazing: "On looking long on an area of scarlet silk of about an inch in diameter laid on white paper … the scarlet color becomes fainter, till at length it entirely vanishes, though the eye is kept uniformly and steadily upon it." Swiss philosopher Ignaz Paul Vital Troxler later corroborated Darwin's observations, using colored patches on a wall. The phenomenon became known as Troxler fading.

Neural adaptation, the mechanism by which neurons decrease or stop their response to unchanging stimulation, is thought to underlie perceptual fading during prolonged gazing at an object or scene. Once the target of interest has vanished, blinks, gaze shifts and even microscopic involuntary eye movements called microsaccades can restore it to perception instantly [see "Shifting Focus," by Susana Martinez-Conde and Stephen L. Macknik; Scientific American Mind, November/December 2011].

Troxler fading and neural adaptation may partly explain Caputo's strange-face illusion. When we gaze long and steady into our reflected face, the unchanging nature of the visual stimulus causes facial features to disappear (and then reappear, as we blink or make involuntary eye movements, thereby "refreshing" our neuronal responses). In the absence of visual information, our brain will "fill in" the gaps according to our experiences, expectations, best guesses, and even hardwired neural mechanisms involved in shape and face perception. The result can be amusing or disquieting.

COURTESY OF AKIYOSHI KITAOKA (*top*); COURTESY OF RYOTA KANAI *Utrecht University* (*bottom*)

+

BEAUTY IN THE EYE OF THE BEHOLDER

Artwork may contain "errors" that are obvious to our central vision but become invisible when viewed from the corner of our eye. Neuroscientist Denis Pelli of New York University discovered that Pablo Picasso's *Maquette for Guitar* (1912) appears absurd only when we look at it directly: the strings are torn and twisted, the neck is crooked, and the body is split into disconnected pieces. But now focus on the cross above while still paying attention to the guitar: all you can see are the smooth curves and elegant angles of a beautiful instrument. Pelli hypothesizes that the illusion works because our peripheral vision confuses the locations of the parts. Failure to notice the errors in the maquette produces the perception of a real guitar. Picasso's paintings of Nusch Éluard, a French acrobat, show a similar phenomenon. When viewed directly, the portraits are grotesque, but when seen peripherally, the young woman looks exquisite. Pelli suspects that Picasso was well aware of this effect.

A few years ago I had the opportunity to collaborate with cognitive scientist Daniel Simons (author, with Christopher Chabris, of *The Invisible Gorilla,* Random House, 2010) and his colleagues at the University of Illinois at Urbana-Champaign on an experiment to investigate visual fading in entire scenes. You can experience the effect by focusing your gaze precisely at the center of the blurry image while paying attention to the entire scene. Careful staring for just a few seconds will minimize your eye movements, causing the scene to fade to gray. Now stop focusing your gaze, and the scene will come right back. Scientists are able to make nonblurred scenes fade in the laboratory by completely removing or by compensating for the observer's eye movements.

THERE GOES THE NEIGHBORHOOD

Stare at the center of this scene for several seconds to make it fade. Then move your eyes freely to revive it.

(Further Reading)

- **The Vanishing of the Sun: A Manifestation of Cortical Plasticity.** Avinoam B. Safran and Theodor Landis in *Survey of Ophthalmology,* Vol. 42, No. 5, pages 449–452; March–April 1998.
- **The Moving Tablet of the Eye: The Origins of Modern Eye Movement Research.** Nicholas J. Wade and Benjamin W. Tatler. Oxford University Press, 2005.
- **Vanishing Act.** Art Wolfe and Barbara Sleeper. Bulfinch, 2005.
- **Induced Visual Fading of Complex Images.** D. Simons, A. Lleras, S. Martinez-Conde, D. Slichter, E. Caddigan and G. Nevarez in *Journal of Vision,* Vol. 6, No. 10, pages 1093–1101; September 26, 2006.
- **Vision and Art: The Biology of Seeing.** Margaret Livingstone. Abrams, 2008.
- **Strange-Face-in-the-Mirror Illusion.** G. B. Caputo in *Perception,* Vol. 39, No. 7, pages 1007–1008; 2010.
- **Shifting Focus.** Susana Martinez-Conde and Stephen L. Macknik in *Scientific American Mind,* Vol. 22, No. 5, pages 48–55; November/December 2011.

© 2013 ESTATE OF PABLO PICASSO/ARTISTS RIGHTS SOCIETY, NY, AND © MUSEUM OF MODERN ART/LICENSED BY SCALA/ART RESOURCE, NY *(top)*; COURTESY OF DANIEL SIMONS *University of Illinois at Urbana-Champaign (bottom)*

Yorick's Ghost
AND OTHER AFTERIMAGES

By Stephen L. Macknik and Susana Martinez-Conde

Staring at images can temporarily reset retinal cells and cause ghostly visions

Alas, Poor Yorick! I knew him, Horatio; a fellow of infinite jest, of most excellent fancy; he hath borne me on his back a thousand times; and now, how abhorred in my afterimage he is!

Well … that's what William Shakespeare's Hamlet might have said, had he been looking at a vintage Pears' Soap advertisement bearing court jester Yorick's skull, rather than holding an exhumed and rotting Danish cranium. Stare long enough at the skull in the ad, and it will be "burned" into your vision even after you look away.

Afterimages such as Yorick's skull help us understand how neurons in various areas of the brain adapt to the visual environment. Adaptation, in this case, is the process by which neurons habituate to, and eventually cease responding to, an unchanging stimulus.

Once neurons have adapted, it takes a while for them to reset to their previous, responsive state: it is during this period that we see illusory afterimages. We see such images every day: after briefly looking at the sun or at a bright lightbulb or after being momentarily blinded by a camera flash, we perceive a temporary dark spot in our field of vision.

COURTESY OF LIVEWIRE PUZZLES www.puzzles.ca

TO SEE OR NOT TO SEE …

YORICK'S SKULL.

An awe inspiring but interesting illusion.

"Now get thee to my Lady's chamber, and tell her, let "her paint an inch thick, to this favour she must come."

HAMLET. Act. V.—Scene 1.

DIRECTIONS TO SEE THE GHOST.

Look steadily, in a good light, for thirty seconds at the mark × in the eye of the skull, and then at a sheet of paper, a wall, the ceiling or elsewhere, and continue your gaze fixedly for another thirty seconds when *an awe inspiring and ghost-like skull will slowly appear!* *By increasing the distance* the apparition will increase in size, so that at five or six feet it will appear of huge proportions.

PRESENTED BY PEARS' SOAP.

COURTESY OF G. SARCONE, © 2002 *(top)*; COURTESY OF ROB JENKINS *University of Glasgow* AND RICHARD WISEMAN *University of Hertfordshire (bottom)*

BOVINE FLY

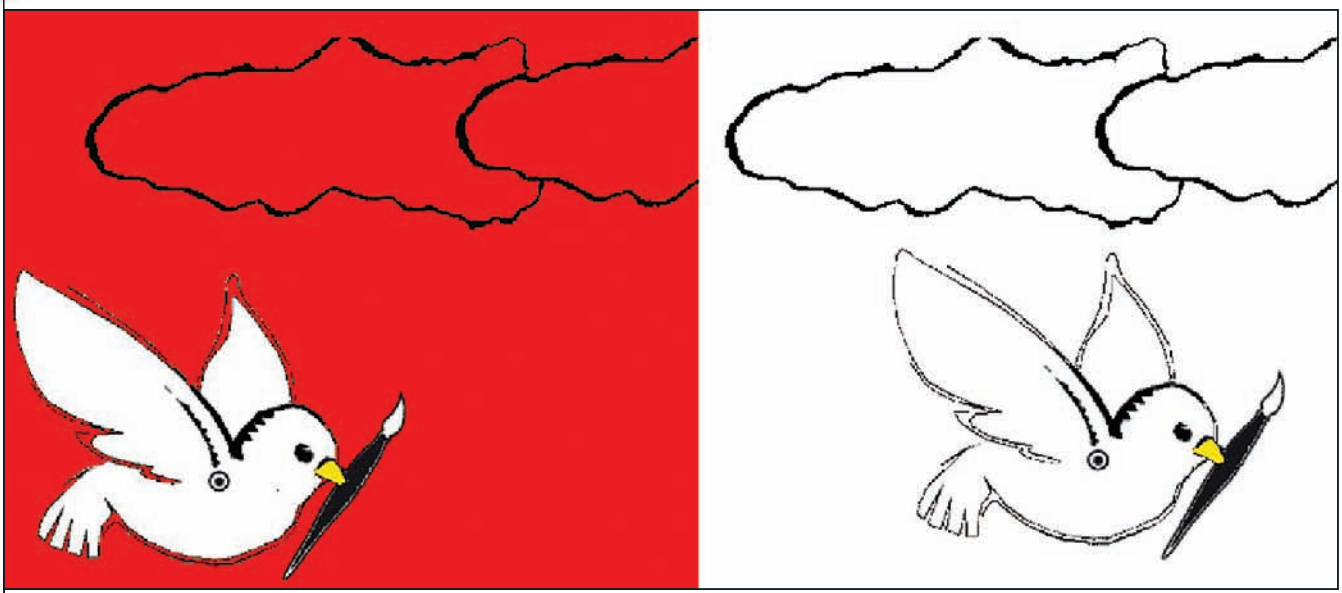
This illusion shows the interaction between color perception and afterimages. First, notice that the left image has a color imbalance to the right and left of the fly: the left side is bluish, and the right side has too much yellow. Now fixate your gaze on the fly in the right image for 30 seconds: this staring will make the neurons in your retina adapt to a blue hue on the left and yellow on the right. As a result, your left visual field will become less sensitive to blue and your right visual field less sensitive to yellow. Then look back at the fly on the cow's nose, and the image will appear to have a perfect color balance. This illusion helps to explain why objects look the same color under different lighting conditions. For example, your shirt looks the same whether you are indoors or outdoors, even though light from a lamp and light from the sun have different color spectra. Your visual system adapts to the illumination and "discounts" it to maintain color constancy. Some of this processing happens in the retina rather than the brain. Notice, too, that the color-selective adaptation is constrained to a single eye: if you close one eye during the adaptation period and then switch eyes while looking at the cow, the color balance will revert to blue and yellow in the unadapted eye.

EVOLUTION AND ADAPTATION

In celebration of the 200th anniversary of Charles Darwin's birth, psychologists Rob Jenkins of the University of Glasgow in Scotland and Richard Wiseman of the University of Hertfordshire in England created an illusory homage to Darwin's evolutionary roots. Stare at the center of the image for 30 seconds, then look away at a white surface. The two monkeys turn into an afterimage of Darwin's portrait! An afterimage is never as sharp as the original. Jenkins and Wiseman took advantage of this difference in resolution to create an image that looks one way in "normal" high-resolution vision and a different way as a lower-resolution afterimage.

To experience this antique illusion (*left*), stare at the X in Yorick's left eye socket for about 30 seconds. Then look away at a flat surface such as a piece of paper, wall, ceiling or sky, and you will see Yorick's afterimage as a ghostly apparition.

Vision scientists believe that the adaptation effect producing poor Yorick's ghost largely takes place in the neurons of the retina. How can we know? Close your right eye and stare at the X again. Then look at the wall again to see the afterimage, but this time switch back and forth between closing one eye and the other. Only the left eye—which was open during the adaptation period—will reveal Yorick's ghost. This means that the adaptation must have taken place only in neurons responding to stimulation from the left eye. If the adaptation had occurred in the binocular neurons of the brain (in the primary visual cortex and higher visual areas), you would see Yorick's ghost with either eye.



A BIRD OF A DIFFERENT FEATHER

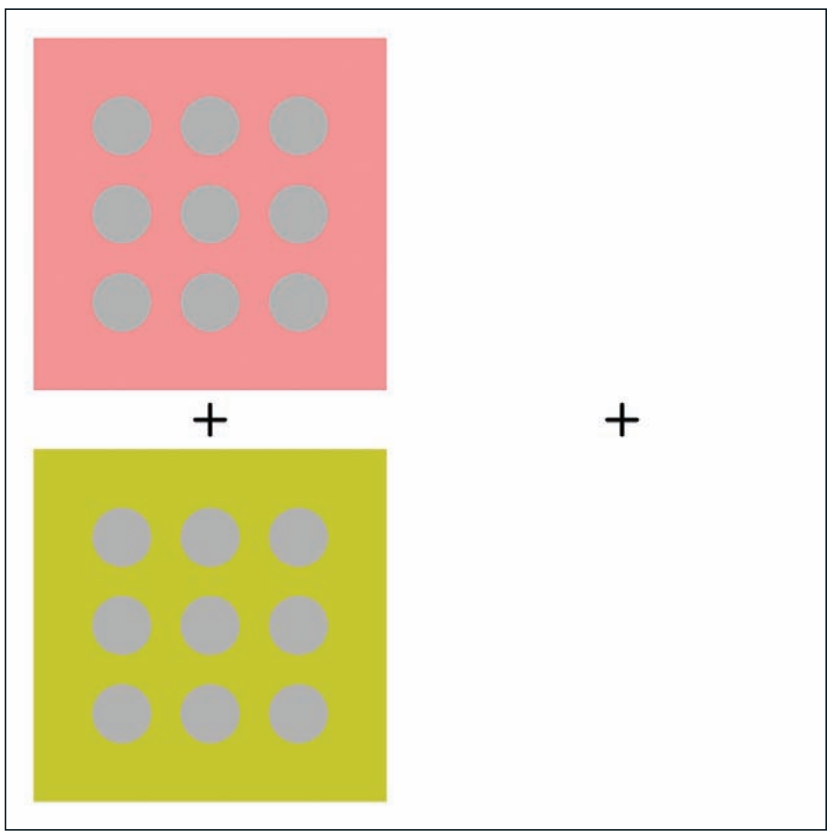
Positive afterimages can be captured from a complementary surrounding color, as in this demonstration of an uncolored bird that captures the reddish color of its background. Stare for about 30 seconds at the "target" on the bird in the left panel. Then look immediately at the same spot on the bird in the right panel.

In this illusion, created by vision scientists Yuval Barkan and Hedva Spitzer of Tel Aviv University in Israel, the red background in the left panel causes the bird to fill in with a complementary blue-green color, which gives rise to a surprisingly strong and long-lasting red afterimage of the bird once the red background is removed.

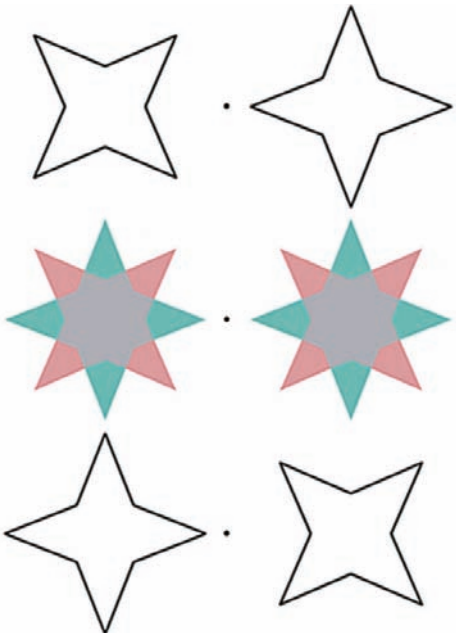
This illusion won second prize in the 2009 Best Illusion of the Year Contest. To experience an even more striking version of this illusion with a "flying" bird, visit http://illusionoftheyear.com/2009/color-dove-illusion

RED AND YELLOW BEADS

Gaze at the cross between the upper and lower squares for about 30 seconds. Then look immediately at the cross on the right, and you should see 18 colored beads: nine red beads above the cross and nine yellow beads below the cross. The beads are all gray in the image itself, but the surrounding colors induce colored afterimages.



COURTESY OF YUVAL BARKAN AND HEDVA SPITZER *Tel Aviv University (top)*; COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University (bottom)*



SHAPE-SPECIFIC AFTERIMAGES

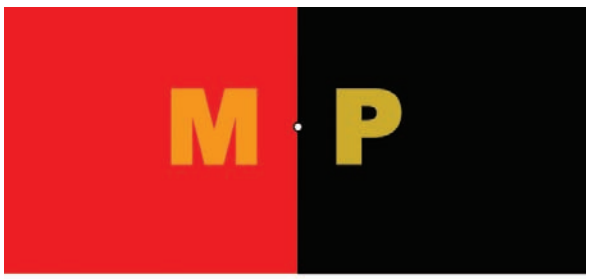
In this illusion a single colored image produces two afterimages of different colors, depending on the shapes you look at afterward. Fixate your gaze on the black dot between the colored stars in the middle panel and stare at it for 30 seconds without moving your eyes. Then look at the empty outlines in the top panel. The left one fills in with a ghostly blue-green, and the right one looks reddish. When you look at the bottom panel, the colors are reversed.

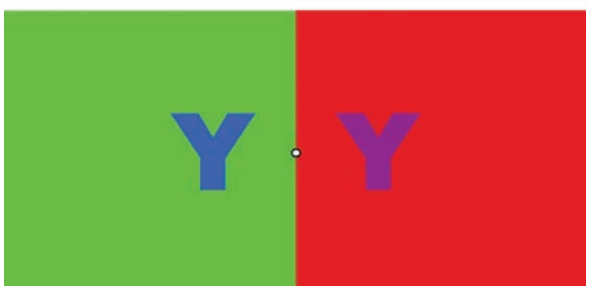
How does one image produce two afterimages of different colors? And how does the shape of the outline determine the filled-in color? The creators of this illusion, Rob van Lier and Mark Vergeer, both then at Radboud University Nijmegen in the Netherlands, have suggested that patches of an afterimage can spread and merge to fill the contours of an outlined shape. The shape at the upper right takes on a reddish hue because it has the same outline as the complementary blue-green patches in the original color image. Likewise, the blue-green-tinged shape at the upper left matches the red patches in the color image. This illusion won first prize in the 2008 Best Illusion of the Year Contest.

See a dynamic version at http://illusionoftheyear.com/2008/filling-in-the-afterimage-after-the-image

NOTHING IS THE SAME

These incredible illusions by Abigail E. Huang, Alice J. Hon and Eric L. Altschuler, all then at Rutgers New Jersey Medical School, and by Christopher W. Tyler of the Smith-Kettlewell Eye Research Institute show that objects of the same apparent color can look like different colors in an afterimage and that differently colored objects can appear to be the same color in an afterimage. Stare at the white spot between the yellow letters M and P in the upper image. Hold your gaze for 30 seconds and then look at a white wall. You will see an afterimage of the letters, which are now magenta (M) and purple (P). In the lower image there are two Y's, one blue and one purple. Look at the white spot between them for 30 seconds and then move your eyes to a white wall. You will now see that the Y's are the same shade of yellow in the afterimage. In fact, the M and P in the upper image are different colors that only look the same shade of yellow because of the effect of the red and black backgrounds. In the afterimage, the complementary background colors—blue-green and white—have the opposite effect: they make the M and P look more different than they really are. The Y's are also different from each other, in the real image, but the complementary background colors in the afterimage make them look like the same color.





LEAST COLORFUL PLACE ON EARTH

Afterimage color assignment works very well with objects to which humans are exquisitely well tuned, such as faces. Gaze for 30 seconds at this reverse-color portrait of John Bortniak, who commanded the South Pole's National Oceanic and Atmospheric Administration Corps (*left*), and then look at the image on the right to see it in color.

FROM "FILLING-IN AFTERIMAGE COLORS BETWEEN THE LINES," BY R. VAN LIER, M. VERGEER AND S. ANSTIS, IN *CURRENT BIOLOGY*, VOL. 19, NO. 8; 2009. REPRINTED WITH PERMISSION FROM ELSEVIER (*top*); COURTESY OF ABIGAIL E. HUANG, ALICE J. HON AND ERIC L. ALTSCHULER *Rutgers New Jersey Medical School* and CHRISTOPHER W. TYLER *Smith-Kettlewell Eye Research Institute*; SOURCE: "METAMERIC INTRANSITIVITY," BY A. E. HUANG, A. J. HON, C. W. TYLER AND E. L. ALTSCHULER, IN *ATTENTION, PERCEPTION & PSYCHOPHYSICS*, VOL. 72, NO. 4; MAY 2010 (*middle*); COURTESY OF JOHN BORTNIAK *NOAA* (*bottom*)

Colors OUT OF SPACE

By Stephen L. Macknik and Susana Martinez-Conde

Colors can change with their surroundings and spread beyond the lines

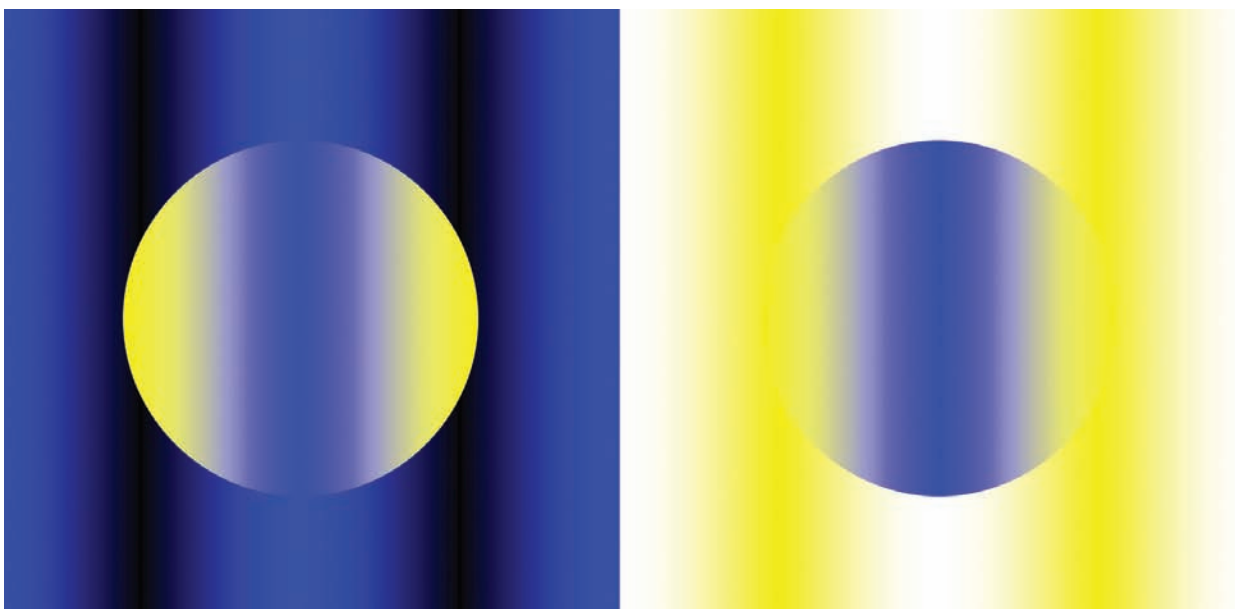
It was just a colour out of space—a frightful messenger from unformed realms of infinity beyond all Nature as we know it; from realms whose mere existence stuns the brain and numbs us with the black extra-cosmic gulfs it throws open before our frenzied eyes.

American science-fiction author H. P. Lovecraft considered *The Colour Out of Space* to be his best story. In this 1927 classic tale of cosmic horror, a small Massachusetts farming community faces unspeakable evil from the outer reaches of the universe. The extraterrestrial villain is not a face-hugging or chest-bursting alien but something far more terrifying: a weird color.

Slowly but surely the otherworldly color mutates and destroys crops, insects, wild animals and livestock. It impregnates the land and the water. The unfortunate farmers who encounter the bizarre hue fall prey to insanity and untimely death.

And you thought vision research was for wimps.

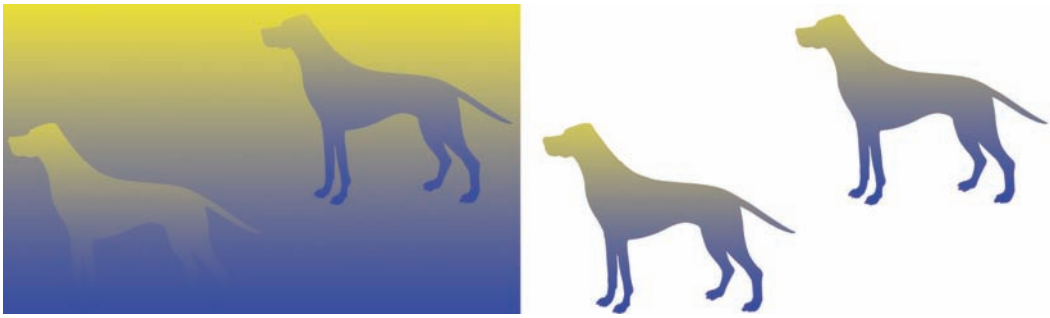
This article features some of the most spectacular color phenomena this side of the galaxy. You won't see any extraterrestrials, but many strange illusions arise from taking colors out of place and putting them in an unusual context. Use caution: the peculiar shades and tints you are about to experience could blow your mind.



COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University*

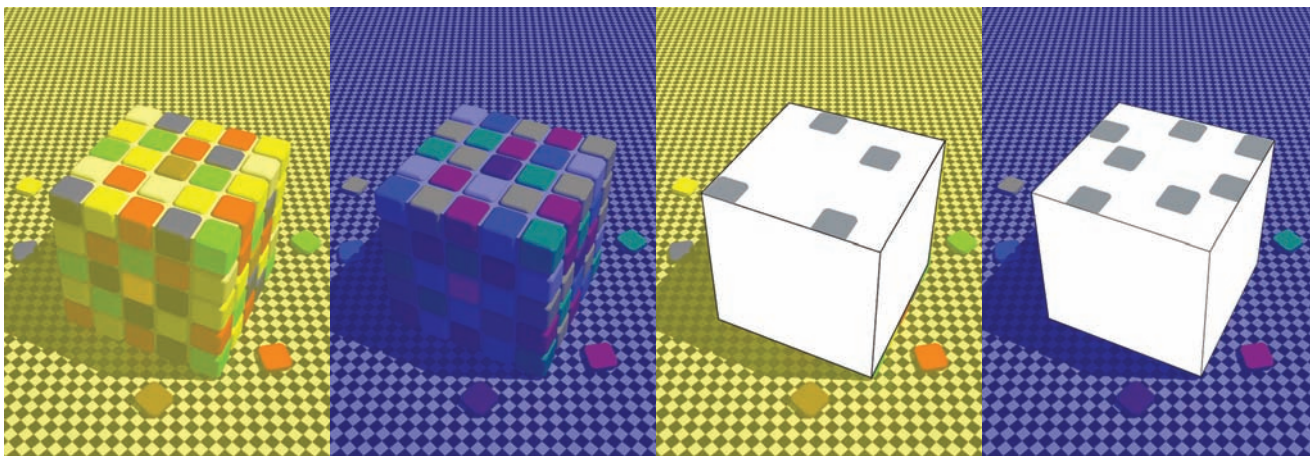
YELLOW MOON AND BLUE MOON

Here we have two moons out of space. One yellow and one blue. Or are they? Actually both moons are exactly the same color in this illusion by psychologist Akiyoshi Kitaoka of Ritsumeikan University in Japan; only the surrounding colors are different. If you don't believe it, cut out the two moons—you'll find them to be identical. The appearance of colors is all about their context.



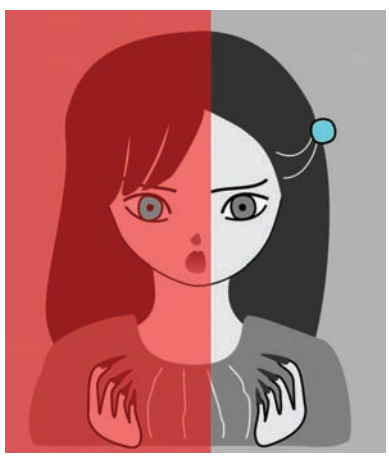
REX AND FIDO

Legend has it that Rome was founded by warring twin brothers, Romulus and Remus, born to a vestal virgin named Rhea Silvia and fathered by Mars, the god of war. Vestal virgins, as it turns out, are not supposed to conceive children, even if the father is a god. The family shame was too much for Rhea's father, who killed her and then condemned the twin baby boys to die of exposure. The wolf Lupa found the boys and adopted them. But hey, what about Lupa's biological pups, Rex and Fido, younger brothers to the feral Romans? These nonidentical twins (*left*) become identical when the background is removed (*right*). Had this pair been born before their mother discovered Romulus and Remus, surely Rome would have gone to the dogs.



RUBIK'S FOLLY

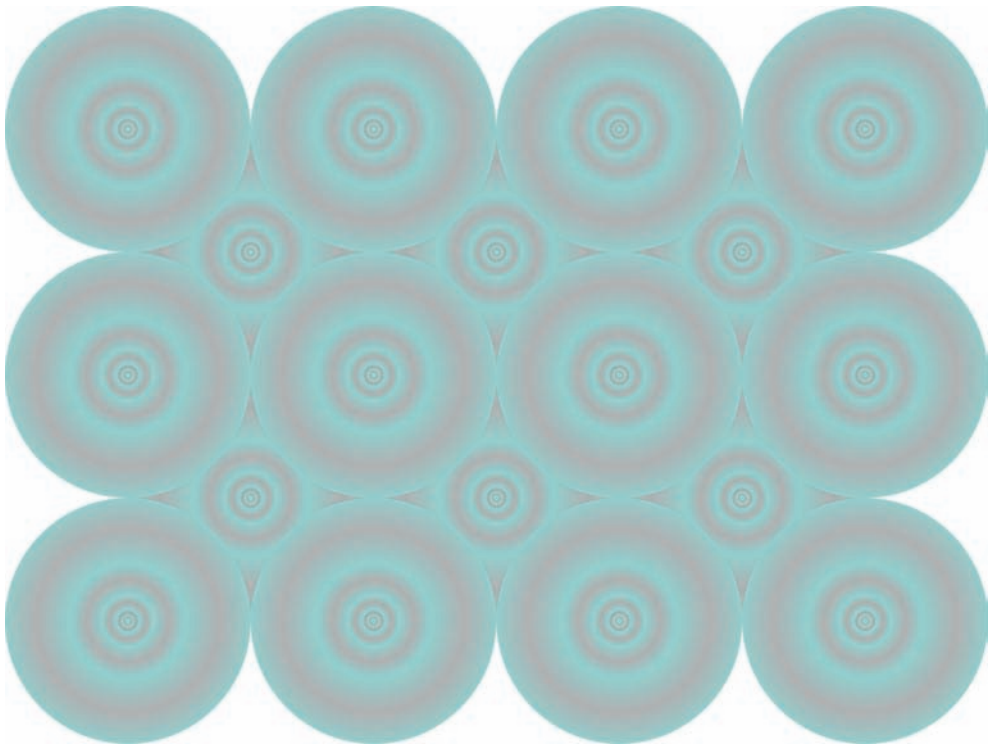
Rubik's Cube is a three-dimensional puzzle in which the player rotates the tiled faces of a cube until each face shows the same color on all nine tiles. Sounds easy? Only if the lighting conditions are stable. As these images by R. Beau Lotto of University College London and Dale Purves of Duke University show, if the lighting changes, it can be hard to know which color is which. The masked version of the images (*above right*) reveals that the blue squares on the left and the yellow squares on the right are actually all gray when viewed under white light. Color perception is not based strictly on the wavelengths of the light that strikes your retina; instead the brain assigns colors based on the lighting conditions and uses the wavelengths only as a guideline to determine which objects are redder or bluer than other objects in the same scene.



EYE SHADOW

It looks like this Japanese *manga* girl has one blue eye and one gray eye. In fact, both eyes are exactly the same shade of gray. The girl's right eye only looks the same as the turquoise hair clip because of the reddish context. Part of the process of seeing color is that three different kinds of photoreceptors in the eye are tuned to three overlapping families of color: red, green and blue (which are activated by visible light of long, medium and short wavelengths). These signals are then instantaneously compared with signals from nearby regions in the same scene. As the signals are passed along to higher and higher processing centers in the brain, they continue to be compared with larger and larger swaths of the surrounding scene. This "opponent process," as scientists call it, means that color and brightness are always relative.

SCIENTIFIC AMERICAN MIND, ADAPTED FROM WWW.MOILLUSIONS.COM (*top*); COURTESY OF DALE PURVES *Duke University* (*middle*); COURTESY OF AKIYOSHI KITAOKA (*bottom*)



RED RINGS

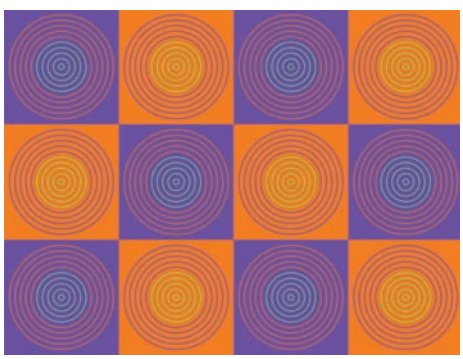
This image by Kitaoka contains a number of blue-green circular structures. The red rings are purely a creation of your brain.

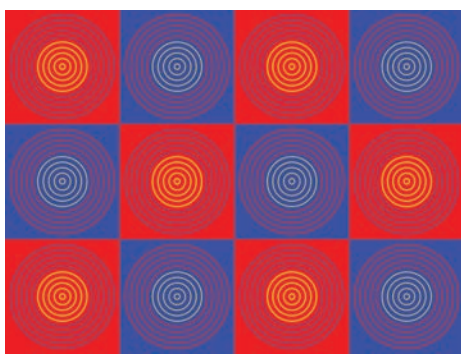
A process called color constancy makes an object look the same under different lighting conditions, even though the color of the light reflecting from the object is physically different. Color constancy is an incredibly important process that allows us to recognize objects, friends and family both in the firelight of the cave and in the bright sun of the savanna.

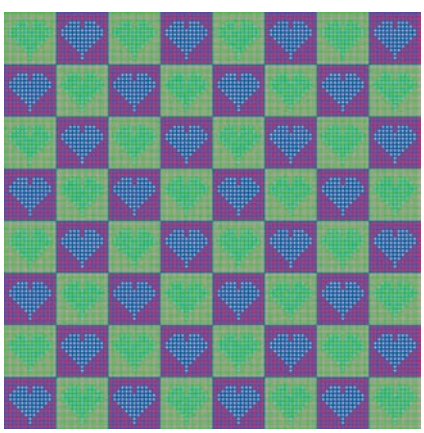
Because the rings here are drawn in shades of blue, the brain mistakenly assumes that the image is illuminated by blue light and that the physically gray rings inside the blue structures must therefore be reddish. The visual system subtracts the blue "ambient lighting" from the gray rings, and gray minus blue results in a pastel red color.

MULTICOLORED RINGS

Here is another example of how the brain determines color depending on the context. In the bull's-eye structures in the left checkerboard, the center rings look either green or blue, but they are all the same color (turquoise). The center rings in the right checkerboard are all the same shade of yellow. Unlike the previous images, this type of color illusion is difficult to explain by an opponent process because the apparent color of the rings is more similar than dissimilar to the background.



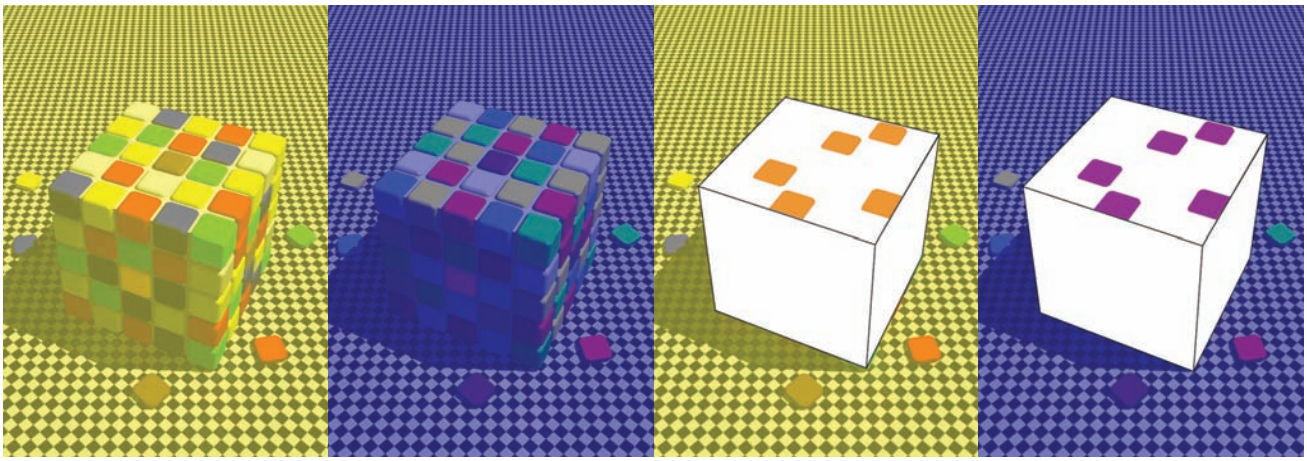




FICKLE HEARTS

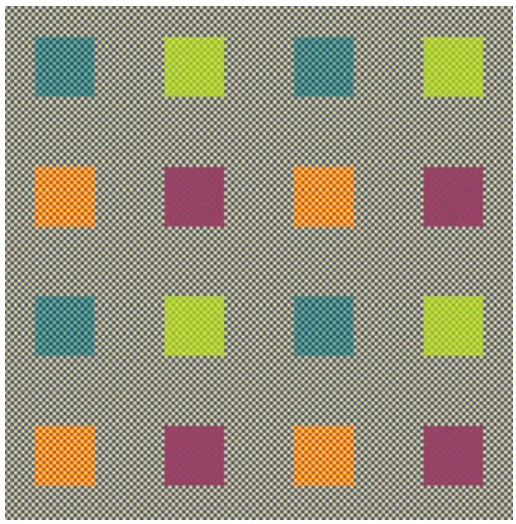
All the hearts in this checkerboard are made out of the same cyan-colored dots, but they look green against the green background and blue against the blue background. The image, by Kitaoka, is based on the dungeon illusion discovered by vision scientist Paola Bressan of the University of Padua in Italy.

COURTESY OF AKIYOSHI KITAOKA



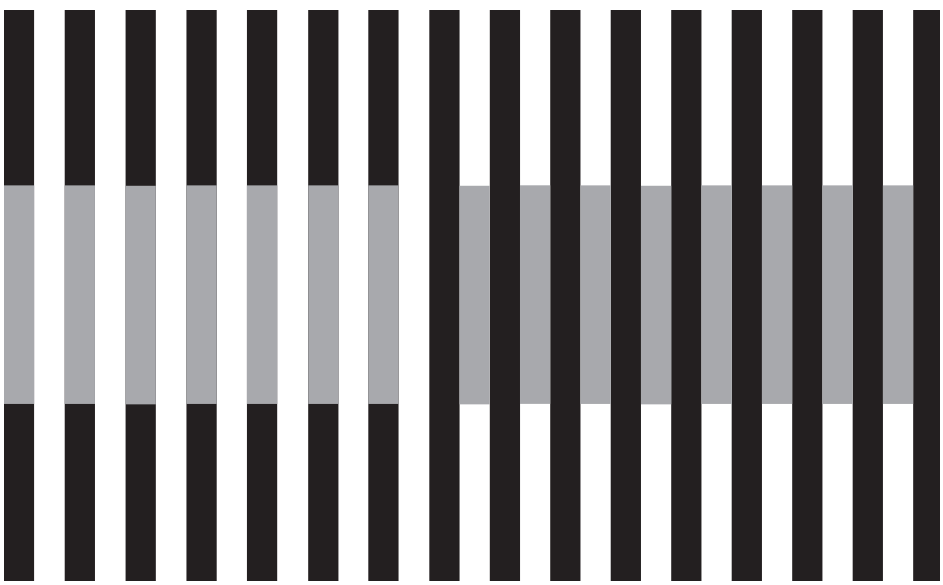
RUBIK'S CONFUSION

We have seen that the same colors can look different from one another, depending on context. These images show that context can also make different colors look similar. Check out the red tiles on the top face of the left and right Rubik's Cubes. They look more or less like the same color. If we mask the rest of the tiles with white (*above right*), you can see that the tiles on the left cube are actually orange and that the tiles on the right are purple.



FOUR WRONG COLORS

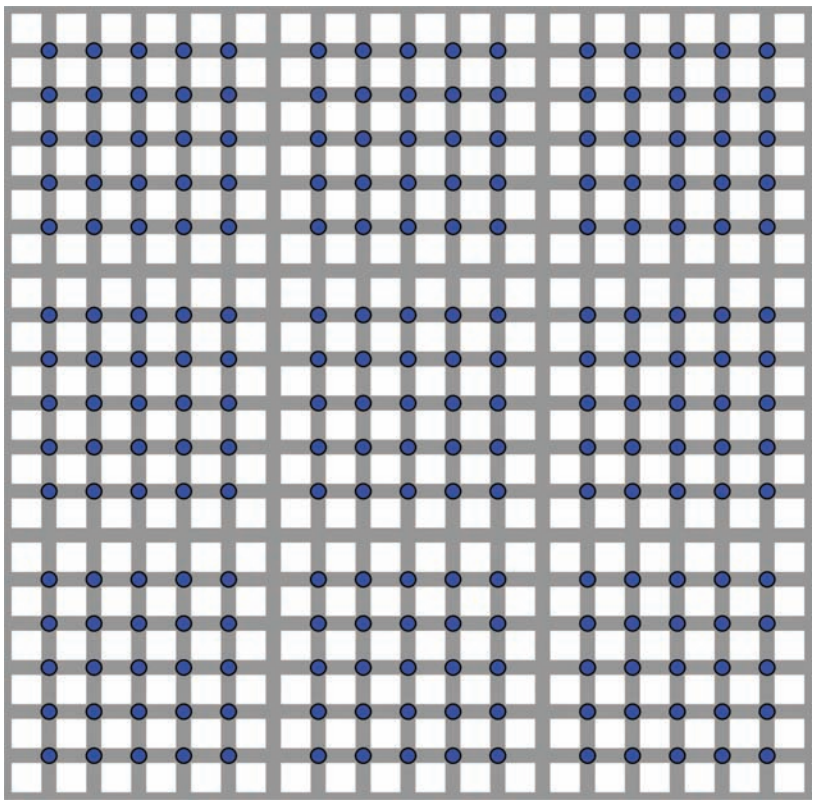
We see four differently colored squares on a gray background, right? Wrong. The gray is actually a mixture of little blue and yellow pixels. Because the pixels are so small, they blend together and do not activate the opponent processes that would create contrast. This is how a color television creates different colors from just a few differently colored pixels (hold a magnifying glass to your TV and prove it to yourself). The turquoise and chartreuse squares are actually little green pixels mixing with either the blue background pixels (turquoise) or the yellow background pixels (chartreuse). Mixing red pixels with either the yellow or blue pixels in the background creates the orange and purple.



WHITE'S EFFECT

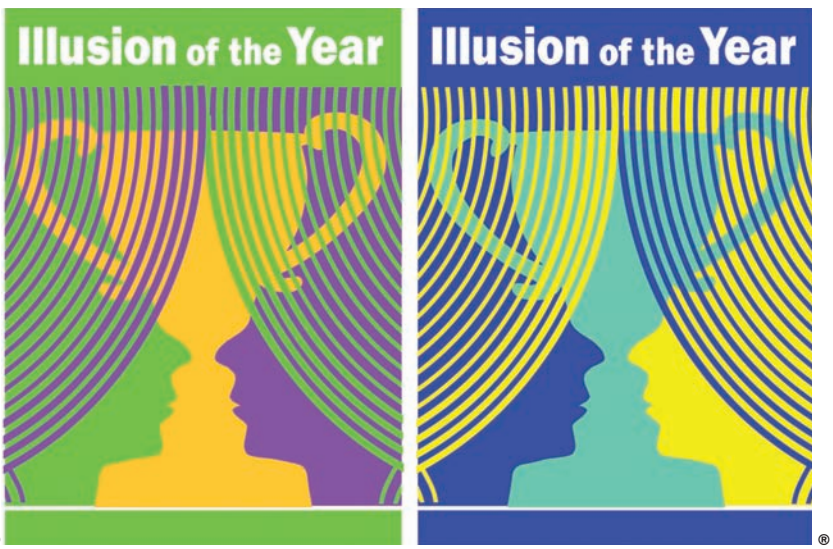
In 1979 Michael White, then at the Tasmanian College of Advanced Education, described an illusion that changed everything in visual science. The gray bars on the left look brighter than the gray bars on the right. In fact, all the gray bars are physically identical. Before White discovered this effect, all brightness illusions were thought to result from opponent processes—that is, a gray object should look dark when surrounded by light and light when surrounded by dark. But in this illusion the lighter-looking gray bars are surrounded by white stimuli, and the darker-looking gray bars are surrounded by black. The brain mechanisms underlying White's effect remain unknown.

COURTESY OF DALE PURVES (*top*); COURTESY OF AKIYOSHI KITAOKA (*middle and bottom*)



SPARKLING COLOR

In *Light of Sapphires,* the blue dots appear to scintillate as you move your eyes around the image. But when you focus on one dot, the scintillation stops. The blue color appears more saturated for the dot in focus than for dots in the visual periphery. This effect is a colorful variant of the scintillating grid illusion discovered in 1994 by Elke Lingelbach, then at the Institute for Optometry Aalen in Germany, and her colleagues Michael Schrauf, Bernd Lingelbach and Eugene Wist.



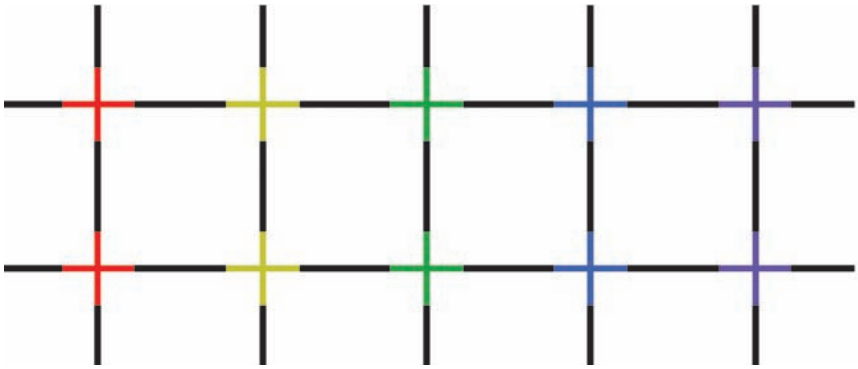
ILLUSION OF THE YEAR

White's effect also affects the way colors look. The logo for the Best Illusion of the Year Contest is a combination of White's effect (the vase appears to be different colors behind the two curtains) and the famous face-vase illusion (in which the "vase" is a trophy for the winner). See more color combinations at http://illusionoftheyear.com

UNREAL SPIRALS

These spirals, created by Kitaoka, are particularly strong examples of White's effect as applied to color. The green and cream-colored spirals (*bottom*) are made from stripes that are physically yellow. In the other two examples above, the stripes are physically red and cyan, rather than purple, orange, blue and green.

COURTESY OF AKIYOSHI KITAOKA (*top left and top to bottom at right*); COURTESY OF NEURAL CORRELATE SOCIETY (*bottom left*)

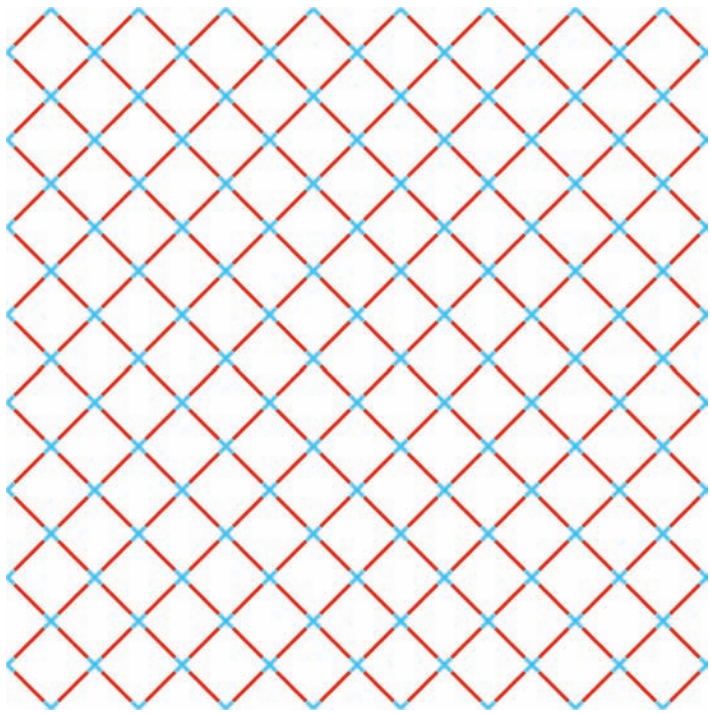


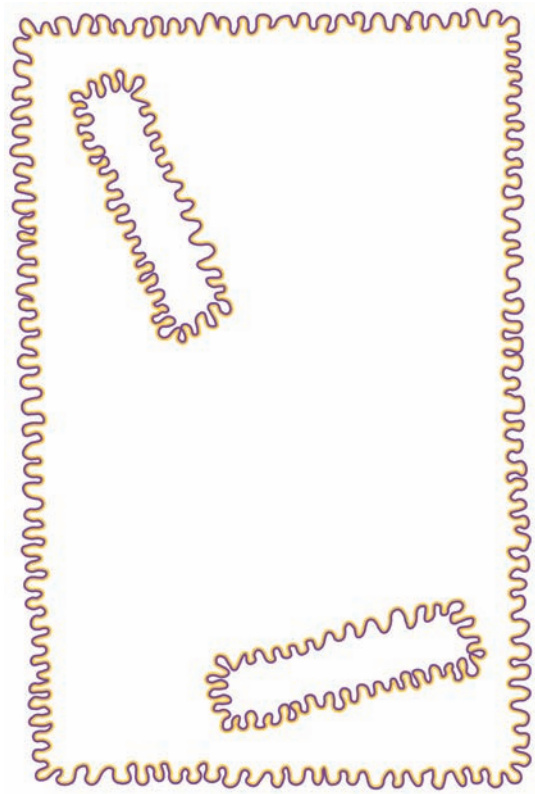
NEON COLOR SPREADING

The colors from the small crosses appear to spread onto the white expanse surrounding each intersection. The effect resembles the glare from a neon light. This illusion was reported in 1971 by Dario Varin of the University of Milan in Italy and a few years later by Harrie van Tuijl, then at the University of Nijmegen in the Netherlands. Its neural causes are currently unknown.

CHROMATIC PINCUSHION GRID

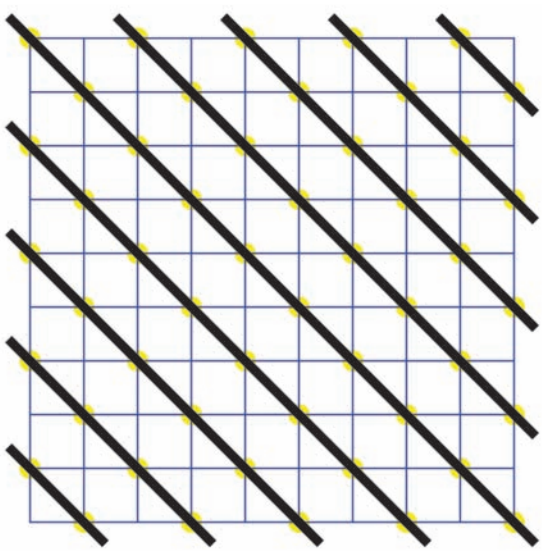
Here the neon color spreading produces a rectilinear grid of north-south and east-west streets on the map—but only in the periphery of your vision. It is absent from whichever intersection you happen to be staring at.





WATERCOLOR EFFECT

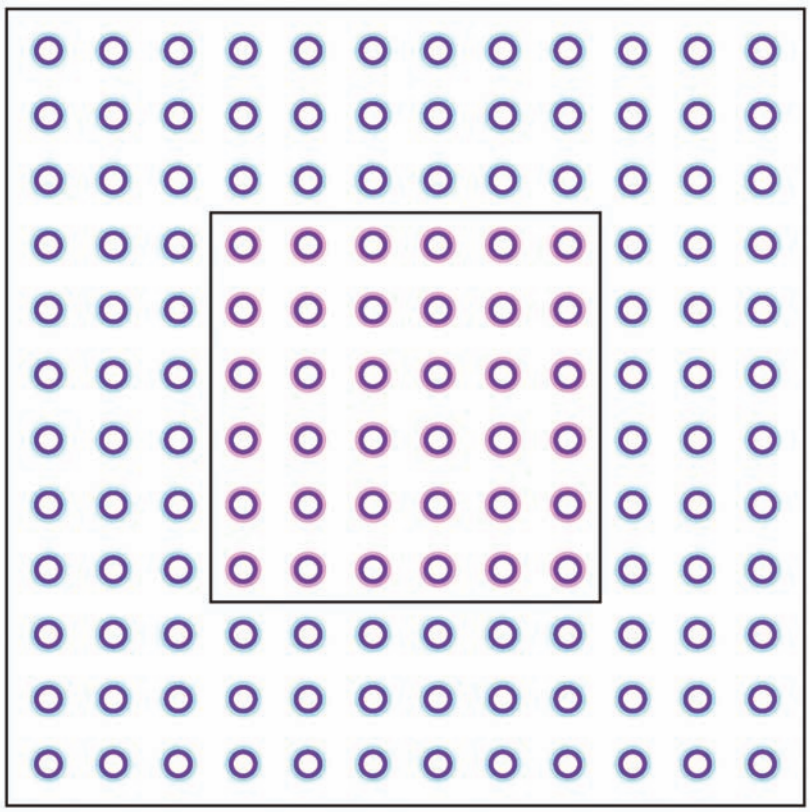
In this illusion by vision scientist Baingio Pinna of the University of Sassari in Italy, a thin, orange contour adjacent to a darker purple contour casts an orange tint over long distances—as though a watery paint was filling in the gaps between the orange lines [see "Illusory Color and the Brain," by John S. Werner, Baingio Pinna and Lothar Spillmann; SCIENTIFIC AMERICAN, March 2007]. On the opposite side of the purple contour, the outlined areas look white.



COLORED RAY

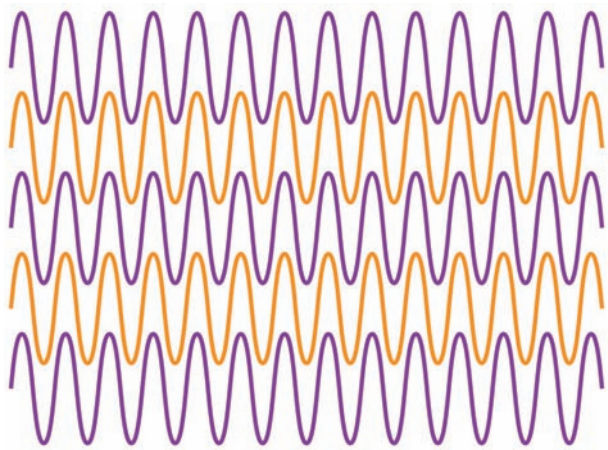
In this neon color spreading illusion, the yellow spreads in a direction that is perpendicular to the black bars.

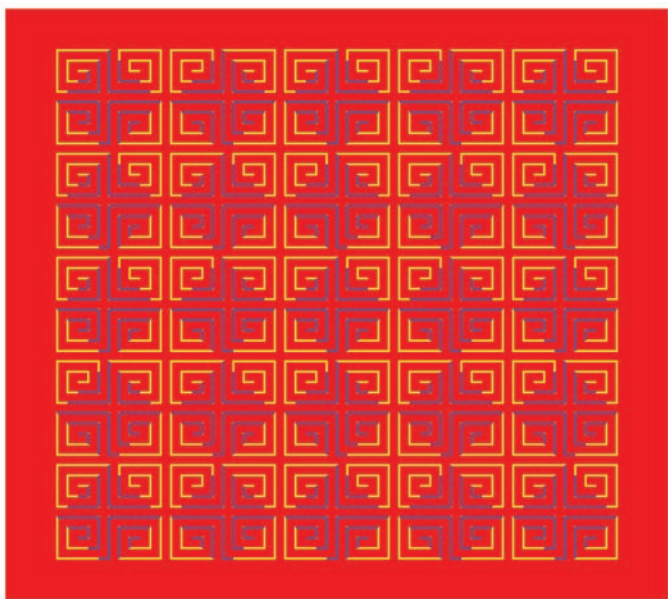
COURTESY OF AKIYOSHI KITAOKA *(top left, middle right and bottom right)*; COURTESY OF BAINGIO PINNA *University of Sassari (bottom left)*



SMOGGY INTERSPACES
In this image by Pinna, the inner square appears to have purple smog around the dots, and the outer square appears to be filled with blue. The illusion is caused by the watercolor effect.

WAVE-LINE ILLUSION
The watercolor effect inspired the wave-line illusion by Japanese vision scientist Seiyu Sohmiya. In this version by Kitaoka, the white background behind the pattern is tinged by the color of the waves.





CHINESE RUG
The red color behind the blue lines appears to be magenta, whereas the same red color behind the yellow lines appears to be orange. This "color assimilation" illusion shows that colors can blend with one another in some situations, rather than contrasting with one another.

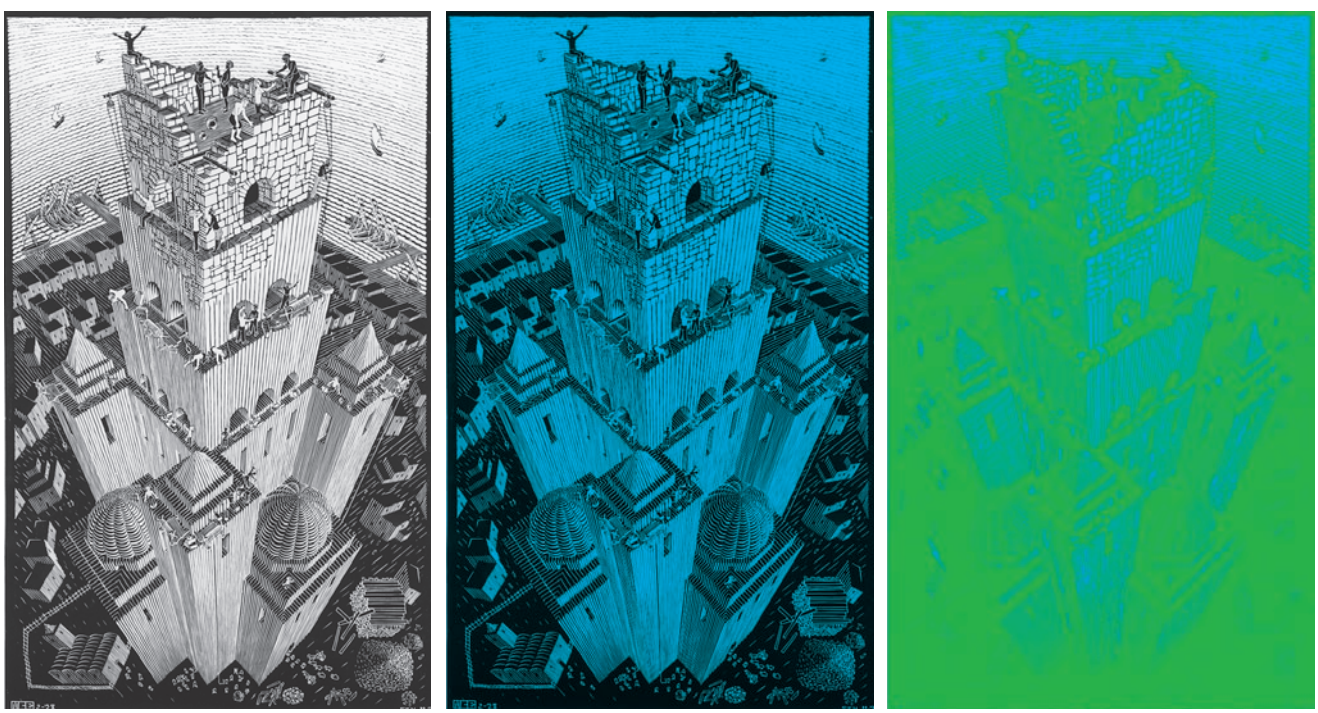
COURTESY OF BAINGIO PINNA (*top*); COURTESY OF AKIYOSHI KITAOKA, FROM "A WAVE-LINE COLOUR ILLUSION," BY SEIYU SOHMIYA, IN *PERCEPTION*, VOL. 36, No. 9; 2007 (*middle*); COURTESY OF AKIYOSHI KITAOKA (*bottom*)

PICASSO'S BLUE PERIOD

During his blue period, Pablo Picasso painted everything—including shadows and gradations of sunlight—in shades of blue (*left*). How do we recognize the people if they are all the wrong color? Margaret S. Livingstone of Harvard Medical School has shown that although Picasso used blue, he was careful to maintain the luminance relations—contrasts in lighting within the scene [see "Art, Illusion and the Visual System," by Margaret S. Livingstone; SCIENTIFIC AMERICAN, January 1988]. Those luminance relations, which we use to make sense of the image, are apparent in a grayscale version of the painting (*right*). This is why color-blind people see just fine in almost every way—sometimes they do not even know they have a deficit.

ESCHER'S COLOR TOWER

Here Livingstone and her Harvard colleague David H. Hubel took an Escher woodblock, *Tower of Babel* (*left*), and colored the white spaces light blue (*center*). You still see the tower because the luminance relations remain intact. But when the black spaces are replaced by a green shade with the same luminance as the blue (previously white) spaces, the 3-D character of the image falls apart (*right*). Our visual system cannot perceive volume, form and distance with only color information available. Luminance information is also required.

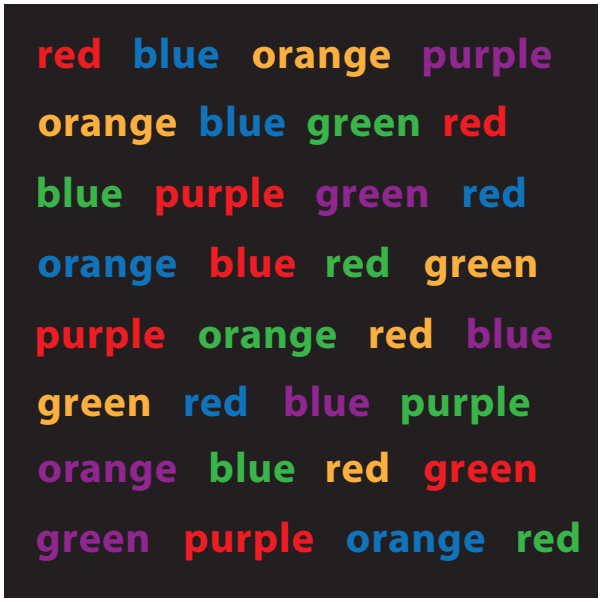


© 2013 ESTATE OF PABLO PICASSO/ARTISTS RIGHTS SOCIETY, NEW YORK, AND SCALA/ART RESOURCE, NY (*top*); M. C. ESCHER'S *TOWER OF BABEL*, © 2013 THE M. C. ESCHER COMPANY-THE NETHERLANDS. ALL RIGHTS RESERVED. WWW.MCESCHER.COM (*bottom*)

PICASSO'S COLOR SPREADING
This painting by Picasso shows that coloring within the lines is unnecessary. Our brain assigns the colors to the correct shapes even though the shapes are depicted minimally with sparsely drawn lines.

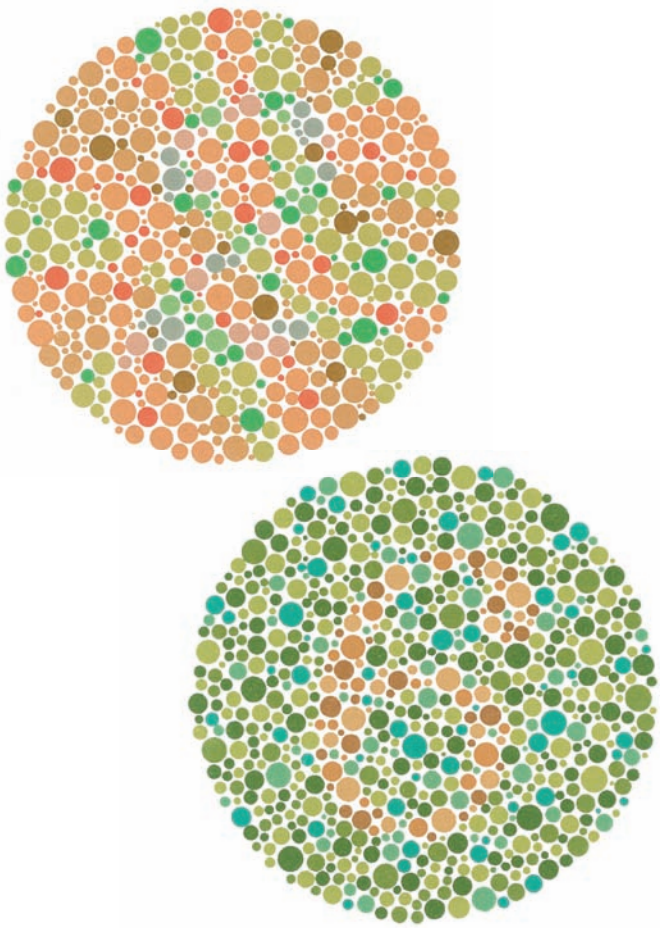
Pablo Picasso, Spanish, 1881–1973
Mother and Child, 1922, Oil on canvas, 39-3/8 x 31-7/8 in (100 x 81 cm)
The Baltimore Museum of Art: The Cone Collection, formed by Dr. Claribel Cone and Miss Etta Cone of Baltimore, Maryland
BMA 1950.279

© 2013 ESTATE OF PABLO PICASSO/ARTISTS RIGHTS SOCIETY, NEW YORK


red blue orange purple
orange blue green red
blue purple green red
orange blue red green
purple orange red blue
green red blue purple
orange blue red green
green purple orange red

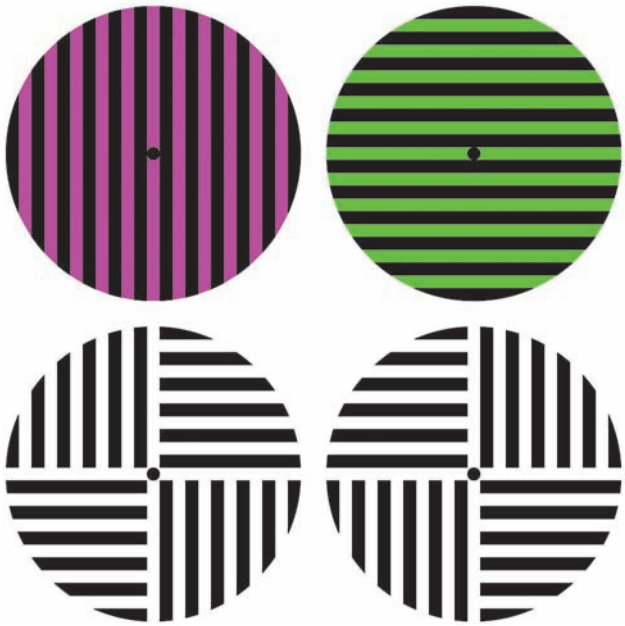
DISCOMBOBULATING COLOR

Here is a great cognitive visual illusion that involves a conflict between the syntactic and symbolic processing systems in your brain. Look at the words one after the other without stopping or slowing, but instead of reading each word, just say its color out loud. It's hard, isn't it? You are experiencing the Stroop effect, named after psychologist John Ridley Stroop. Even if you try not to read the words, you cannot keep the content of the words from conflicting with their color.



COLOR BLINDNESS TEST

Japanese ophthalmologist Shinobu Ishihara developed 38 color plates, including the two above, to test patients for color blindness. Each plate is a circle filled with dots of different sizes and colors. People with the most common types of color blindness find it difficult or impossible to see the numbers hidden within the patterns shown here.



THE McCOLLOUGH EFFECT

Discovered by vision researcher Celeste McCollough, this illusion demonstrates that the interactions between color perception and form perception can be surprisingly long-lasting. The effect takes discipline, though, so suck it up before you try it, soldier! We can't make you do it, of course, but it won't work correctly unless you do, and we promise it will be worth the effort.

Look at the black dot at the center of the vertical magenta-striped grating for one full minute. (One minute will seem like forever, but trust us on this.) Then fixate on the dot in the horizontal green grating for one minute. Then shift back to the vertical magenta grating and then back to the green, for one minute apiece. Repeat another cycle. Okay, now you're ready. After six minutes of alternating between the two gratings, look back and forth between the uncolored patched gratings below. You will see that the horizontal patches are tinged magenta and that the vertical patches are tinged green.

This illusion shows that adaptation, the process by which neurons in the brain become less responsive to unchanging stimuli, can be simultaneously selective for both color and orientation of edges. That is, you have neurons that are attuned to both magenta and vertical orientations, and when you stared at the vertical magenta grating for minutes on end, that allowed the horizontal-detecting neurons that are sensitive to magenta to seem more responsive. So when you are presented with a horizontal white grating after the adaptation, it looks tinged with magenta. The same is true for the green adaptation, for the opposite orientations.

McCollough's illusion was the first to show that adaptation can last a long time. If you come back in an hour and look at the white gratings, you will still see an effect, albeit weaker.

SCIENTIFIC AMERICAN MIND; SOURCE: "STUDIES OF INTERFERENCE IN SERIAL VERBAL REACTIONS," BY JOHN RIDLEY STROOP, IN *JOURNAL OF EXPERIMENTAL PSYCHOLOGY*, VOL. 18: 1935 (*top*); COURTESY OF AKIYOSHI KITAOKA (*middle*); FROM *TESTS FOR COLOUR-BLINDNESS*, BY SHINOBU ISHIHARA. HANDAYA, TOKYO, HONGO HARUKICHO, 1917 (*bottom*)

THE Aviator's DILEMMA

By Stephen L. Macknik, Susana Martinez-Conde and Ellis C. Gayles

Military aviators learn to second-guess their senses

The leans, one of the most common vestibular illusions, occurs when the inner ear organ responsible for balance, the semicircular canal (*pink rings*), fails to continue to detect movement during a lengthy turn. As the aircraft turns, at first the endolymph fluid in the canal lags behind the turn, bending a hair cell (*green*), which signals the movement to the brain (*left*). In a prolonged turn, however, the vestibular system no longer detects the inertial difference between the canals and their fluid and no longer transmits the turning information to the brain (*center*). As the plane rolls out of the turn, the inertial difference between the fluid and canal reemerges but causes the misperception of turning in the opposite direction.

GETTY IMAGES (*opposite page*); COURTESY OF LCDR BRIAN D. SWAN, USN (RET.) (*this page*)

MAJOR PAUL "Goose" Gosden, U.S. Marine Corps, piloted his UH-1 Huey close air support helicopter across the Kuwait-Iraq border through the night's oily blackness. His aircraft was first to cross into Iraqi airspace in the second Gulf War, in support of Cobra attack helicopters tasked to destroy observation posts on Safwan Hill, near the infamous Highway of Death. Their mission was the opening salvo of Operation Iraqi Freedom, designed to kick in the door for the U.S. Army's Third Infantry Division, which would follow in a ground assault from Kuwait into Iraq. The Iraqi forces, however, anticipated the aerial sortie and had begun to destroy oil fields, filling the night air with oil smoke and haze so thick that it blinded the marines.

Military flight training ingrains night flying so deeply that pilots can do it practically in their sleep. Flying through an oil cloud at night, on the other hand, definitely ups the pucker factor. "Saddam had exploded the oil rigs to fill the air with oil. I couldn't see the Cobra in front of me or the stars or the moon. It was just black," Gosden recalls. To give yourself an idea of this feeling, start a mission in the helicopter combat Xbox game Apache (which one of us, Macknik, diligently toiled over as "research" for this article). Fly very high over enemy territory, then turn off your television (but not the Xbox) and try to land your helicopter blind as the bad guys begin to shoot at you. Remember, to simulate the experience of Gosden and his crew, you have to commit to actually killing yourself if your simulated copter crashes; otherwise it's just a game.

Spatial D and the Leans

Gosden is telling his hair-raising tale at the Aviation Survival Training Center at Marine Corps Air Station Miramar near San Diego during a course one of us (Gayles) teaches. This air station was the storied home of the U.S. Navy's ("Top Gun") Fighter Weapons School, featured in the 1986 Tom Cruise movie.

Gosden—coincidentally "Goose" is the call sign of Cruise's wingman in *Top Gun*—continues, "We all had 'spatial D' or were suffering from 'the leans.'" Spatial D is short for spatial disorientation, a catchall term to describe the summed result of the various perceptual illusions and degraded sensory perceptions that may occur on a mission. It is the total failure of situational awareness and, shockingly, the most common cause of crashes in the navy, accounting for almost 80 crashes between 1990 and 2008.

Performance fails because pilots can no longer pay attention to what is happening—everything is off-kilter. All they can do is scan the instruments continually to give themselves as much factual information about the aircraft as possible, to counteract the false information from deceitful bodily senses.

The leans is not a colorful military term for gastrointestinal distress, although the two phenomena are, unsurprisingly, often experienced together. Rather the leans is a type of somatogyral illusion you feel in flight when your vestibular system (the inner ear organ responsible for balance and your sense of traveling through space) and your somatosensory system (skin and other bodily positioning sensors) together fail to provide you with an accurate description of where gravity indicates is down.

The illusion happens when you come out of a tight acrobatic turn and the fluid in your vestibular semicircular canals system continues to flow even though you are no longer turning. As a result, you may feel like you are flying straight when in fact you are in a turn, something that investigators concluded happened when John F. Kennedy, Jr.'s plane crashed at Martha's Vineyard in 1999. Technically, the leans is the name of a solution to the problem: leaning your head until your instruments match your perception. Even so, most pilots use the term to relay the problem rather than the solution.

To get an idea of how critical your vestibular system is to your vision, hold up one finger in front of you at arm's length, then look at it as you rotate your head back and forth. Fine, no problem: your finger is nice and clear. Your vestib-

ular system tracked the turning of your head and gave your eyes the information to stay on target. Now hold your head still and move your finger back and forth while following it with your eyes. Now there is no vestibular input because your head is stationary, so your finger becomes blurry. Motion sickness arises from a mismatch between vision and vestibular perception and is a major component of spatial D.

Iraqi Nightlife

Gosden survived his mission by virtue of using his aircraft's forward-looking infrared (FLIR) optical array, which gave him the ability, in tandem with skill and luck, to notice a line of infrared lights marking a column of American light armored vehicles (LAVs) on the ground. He could not see the ground, but the LAVs gave him just enough information about the landscape to allow him to land "safely"—that is, behind enemy lines in the middle of the desert surrounded by a high-speed battle.

"I knew that the ground behind those LAVs must be flat, meaning we could land there. We knew our position was behind enemy lines. But we didn't care—we had completed our flying for the evening. The other pilot on my helicopter, Captain Rodney 'Dino' Dean, was suffering from vertigo, which had the opposite result to what was happening to me [the leans]. It was a miracle we got down," Gosden says. "After landing, we got our weapons and set up a perimeter around the aircraft. When the sun came up, we could see well enough to fly out."

The fog—or dust—of war can have pilots fighting their own senses and reliant on instruments, which are also badly degraded by a brownout.

Training to Survive

Night-vision devices such as personal goggles or the FLIR viewing system that Gosden used can ameliorate spatial D at night, but their performance is highly dependent on illumination, terrain contrast and particulates in the air. For instance, these devices offer little help during brownout conditions, where dust can severely degrade visibility. The main defense that pilots have against the dangerous misperceptions and illusions reviewed here is simply the awareness that they can happen.

Back at the Miramar station, the architecture of the training facility is vintage 1950s U.S. military, the lobby festooned with uniformed mannequins in ejection seats. The lecture hall decor is exactly what you would find on the Boat (navy lingo for an aircraft carrier): overengineered steel recliner-size seats bolted to the floor, padded generously with genuine Naugahyde coverings. Flight suits abound.

"When naval aviation was young, we were crashing two planes a day," Gayles observes, "mostly caused by inevitable equipment failures. Now we crash 20 planes a year or so, and every crash is a very big deal, covered by the press, and reported throughout the military. Most crashes are no longer the result of maintenance or equipment failures. Those problems have been reduced to the point that the main issue is human error. Pilots sometimes fly perfectly good aircraft into the ground."

As important as visual input is for a pilot, **eyes can lie.** False "horizons" are everywhere.

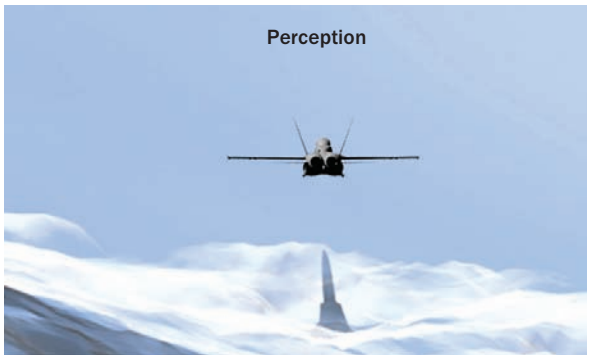
And why does that happen among the most highly trained pilots in the world? The answer: every sensory and cognitive system is highly taxed when flying military aircraft. Visual illusions alone accounted for about 20 crashes from 1990 to 2008, making the combined contribution of illusions of all types twice as high as the next biggest crash cause: fatigue.

This challenge is why Gosden and this group of aviators are here today, to receive their once-every-four-years refresher in situational awareness, aviation physiology and crash-survival training. They are lectured, questioned and then dunked unceremoniously into a huge, cold saltwater pool inside a crash simulator while wearing a blindfold. It's scary, and the only people having fun are the two of us (Martinez-Conde and Macknik) on the side of the pool looking in.

Shifting Horizons

As important as visual input is for a pilot, eyes can lie. For example, when flying above a cloud deck, there is a natural tendency to perceive any relatively straight line in the visual field as a horizon—which can lead to very undesirable results in a fast-moving aircraft.

FROM "A DUAL-MODE SENSOR SOLUTION FOR SAFE HELICOPTER LANDING AND FLIGHT ASSISTANCE," BY YAN CHRISTIAN VENOT AND PETER KIELHORN, IN *MICROWAVE JOURNAL*; JANUARY 17, 2008



Pilots have a natural tendency to consider any straight line in the cloud deck as a false "horizon." Unfortunately, the illusion that a cloud deck is the true horizon can overwhelm the senses, requiring pilots to concentrate on instruments; coastlines, ridge lines and even well-lighted highways can also cause this dangerous effect.

False "horizons" are everywhere around you in the clouds. Your aircraft's attitude may seem level, even if you are tilted and in a turn. Mountain ridges might lead you astray as well, and at night the combination of clouds, stars, mountains and lights on the ground can produce impossibly confusing percepts that lead the aircraft away from the safety of true straight and level flight.

Don't think that you are safe from your own perception, however, just because you are flying above water on a clear day. A fixed horizon can still put you in the drink. Consider what may happen if you approach the beach from over the horizon. You may line up the beach in your sights and then keep it there in anticipation of going "feet dry" (flying from over sea to over land), but if you do so, you will never reach land: the beach is fixed, unlike a true horizon, and the only way to keep it stationary in your sight is to point your aircraft progressively downward.

Beaches make a particularly insidious false horizon illusion. Because they are in a fixed location, the pilot will tend to point the aircraft ever downward to maintain the horizon ahead.

Choosing a fixed horizon in proximity to wires or cables stretched across a valley is especially problematic. As you approach the fixed horizon (such as where a valley floor and mountain wall meet), you slowly and unnoticeably nose down. As you descend, the approaching wires will appear to rise as if they will pass well above you, whereas in fact they remain well below the aircraft. If you don't spot the wires until they are very close (because of mountain haze or the fog of war), your natural reaction may be to push the stick forward to dive under the wires. This is what happened to the U.S. Marine pilots of an EA-6B Prowler aircraft on a training mission in 1998 near an active Italian ski resort in the Alps. The aircraft sliced through two wires, which held a cable car holding 20 skiers 370 feet above the ground. None survived.

One might think that objective information from instruments is the logical solution to subjective sensory illusions. The proliferation of instrumentation is part of the problem, however, because of mounting attentional demands on the pilots, which cause cognitive overload during combat and other stressful flight scenarios. This kind of mental distress is an important contributor to spatial D. New avionics are designed with simplicity, not complexity, in mind, and pilots learn how to scan their instruments at just the right times, under conditions of simulated duress. Systematic instrument scanning demands discipline, which may be one of the first casualties of battle, but until we learn better ways to overcome insidious in-flight illusions, it is one of the main techniques that keep pilots and crews safe.

We would like to thank LCDR Brian D. Swan, USN (Ret.), CDR Tyson Brunstetter, USN, and CDR Fred R. Patterson, USN (Ret.), for their ideas and contributions to this article.

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COURTESY OF LCDR BRIAN D. SWAN, USN (RET.) (*top*); COURTESY OF LCDR BRIAN D. SWAN, USN (RET.). SOURCE: CDR FRED R. PATTERSON, USN (RET.) (*bottom*)

Afraid OF SHADOWS

By Stephen L. Macknik and Susana Martinez-Conde

Spooky illusions trick and treat your brain

What difference do it make if the thing you scared of is real or not?

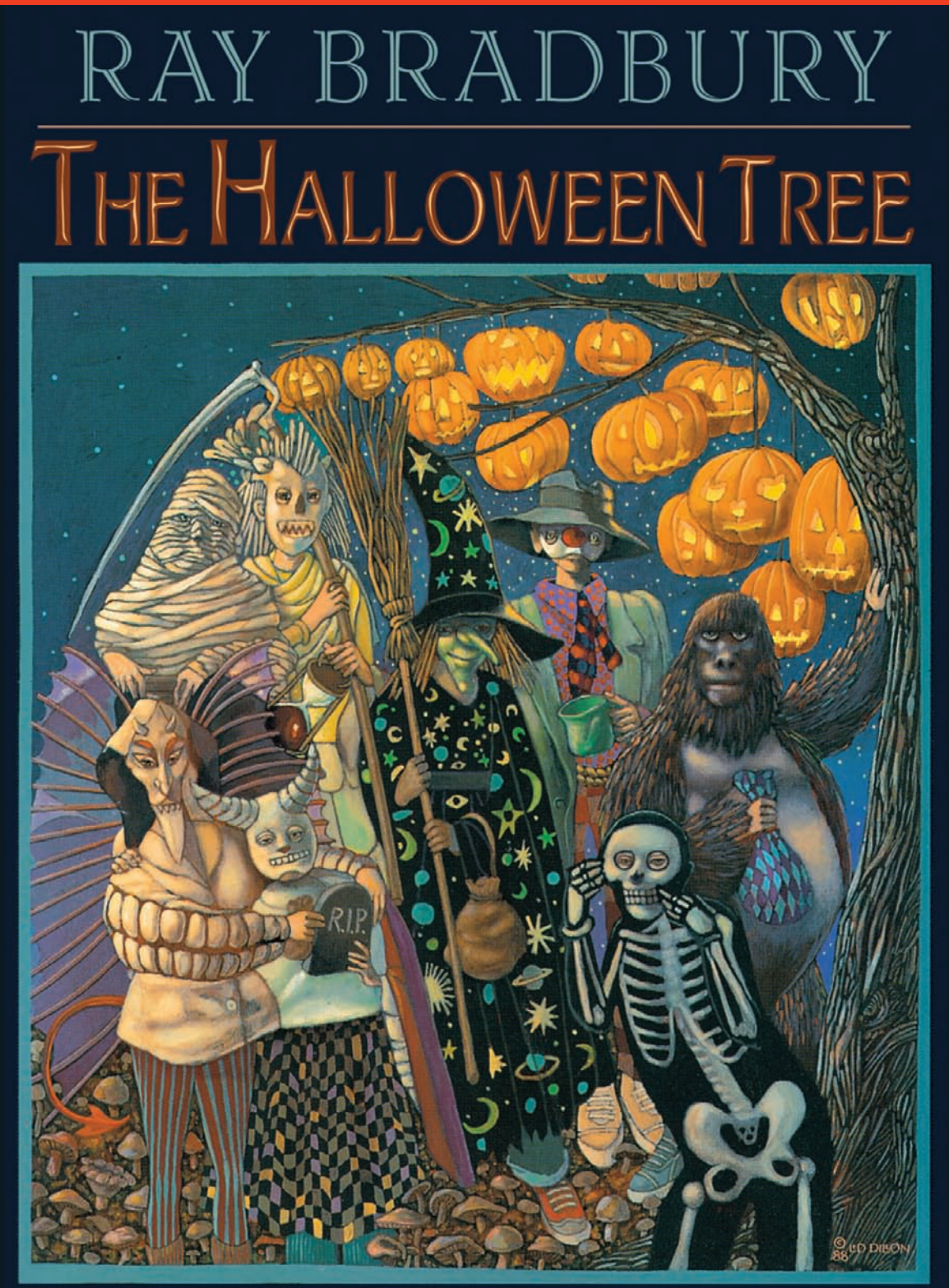
—Toni Morrison, *Song of Solomon*

Halloween celebrates illusion. Even if we manage to ignore flights of fancy the other 364 days of the year, come October 31 we set out to enjoy trickery and pretense. We disguise ourselves, we carve malevolent expressions in bland, innocuous pumpkins and we do our best to suspend our disbelief as we enter supposedly haunted houses. We become illusion creators as well as willing victims. We seek fake fear. But costumes for our masquerades are not the only deceptions that Halloween brings you. Any emotion you experience, whether it be fright or delight, is real only in your mind. In a neural sense, all of us are afraid of "ghosts"; we all have irrational fears that are disconnected from fact (bugs and small spaces are some of our own personal phobias). With its harmless thrills and scares, Halloween pushes gently on the limits of the reality that our brain constructs. And one thing about limits, as Michael Jordan said in his Basketball Hall of Fame induction speech in 2009, is that "like fears, [they] are often just an illusion."

ALL IS VANITY

***All Is Vanity,* an 1892 drawing by American illustrator C. Allan Gilbert (*left*), draws on the 16th- and 17th-century European *vanitas* painting tradition, in which still-life objects symbolize the transient and meaningless nature of earthly pursuits. The woman admiring herself in the mirror does not realize that her bottles of perfume, her makeup table (also called a vanity), her elegant gown, even her own youth and beauty, are fleeting illusions. Only death, represented by the skull engulfing the scene, is permanent and real. *Last Days of the Sun,* by British sculptor James Hopkins (*right*), puts a contemporary spin on the *vanitas* concept. The seemingly casual arrangement of rock-star bling signifies the futility of ephemeral fame and riches. The skull emerging from the image provides the set of items with symbolic meaning.**

C. ALLAN GILBERT, 1892 (*left*); COURTESY OF JAMES HOPKINS (*right*); COURTESY OF RANDOM HOUSE (*opposite page*)



TRICK-OR-TREATERS

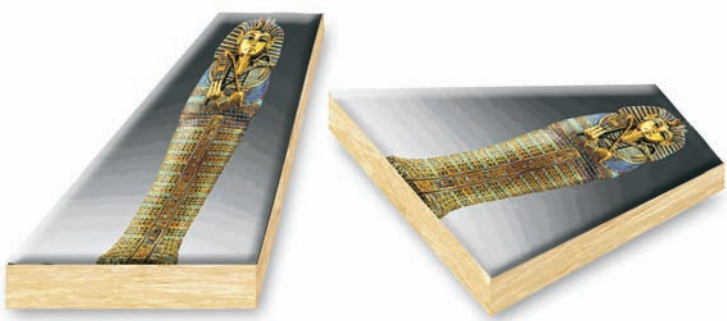
In *The Halloween Tree,* a 1972 novel by the late American horror, science-fiction and fantasy writer Ray Bradbury, eight children go trick-or-treating. Can you find them in the book's cover? In this ambiguous illusion, the costumed kids, their props and the tree in the background form the shape of a skull. Step back from the scene or squint your eyes if you have trouble seeing the skull. To identify the trick-or-treaters, get close again, paying attention to the details in the image. When your perception of an ambiguous image flips back and forth between two possible interpretations, so does the underlying neural activity in the areas of your brain that are responsible for your experience.

WHAT LURKS IN THE SHADOWS

Gestalt psychologists famously asserted that the whole is different from the sum of its parts. British artists Tim Noble and Sue Webster's *Dark Stuff* agglutinates the bodies of 189 mummified animals, including 67 field mice, five adult rats, 42 juvenile rats, 44 garden shrews, a fox, a squirrel, a weasel, 13 carrion crows, seven jackdaws, a blackbird, a sparrow, a robin, a toad, a gecko and three garden snail shells. As anybody would agree, the outcome is so much more than the sum of its body parts.

THE CURSE OF THE MUMMY

"Wretchedness and death will befall to those who disturb the rest of the Kings!" Before you dismiss the Curse of the Twin Pharaohs as nonsense, take a careful look at the two sarcophagi and see if you can detect any signs of evil sorcery. The left sarcophagus appears longer and narrower than the one on the right, and the left mummy image is taller and skinnier than that of the other mummy. Or is this the case? Grab a pair of scissors and cut around the trapezoid shapes on top of each sarcophagus. Now rotate them and superimpose them. Both mummies and sarcophagi are exactly the same size. The effect is a variant of the classic Shepard tabletop illusion, in which two identical parallelograms with orthogonal orientations to each other appear dissimilar in shape. Images drawn inside the parallelograms, such as the mummies in the sarcophagi, are assimilated into the Shepard illusion, so that they, too, appear distorted.



COURTESY OF TIM NOBLE, SUE WEBSTER AND BLAIN SOUTHERN (*top*);
COURTESY OF DANIEL PICON (*bottom*)

COURTESY OF VILLAFANE STUDIOS

OUTRAGEOUS PUMPKINS

American sculptor Ray Villafane competed as one of four professional pumpkin carvers and bagged the Grand Prize in the Food Network's *Challenge* show, *Outrageous Pumpkins,* in 2008 and in *Outrageous Pumpkins Challenge 2* in 2010. He has since carved pumpkins around the world, including in the president's White House quarters. For Halloween 2011 he established a new world record for carving the heaviest pumpkin ever documented. The beast, grown by Jim Bryson and his daughter Kelsey, weighed in at 1,818.5 pounds. Villafane sculpted zombies from a smaller pumpkin (weighing a mere 1,693 pounds) and staged them to create the illusion of the living dead bursting out of the colossal squash pod.

See the artist in action at www.visualnews.com/2011/10/29/halloween-worlds-largest-pumpkin-carving

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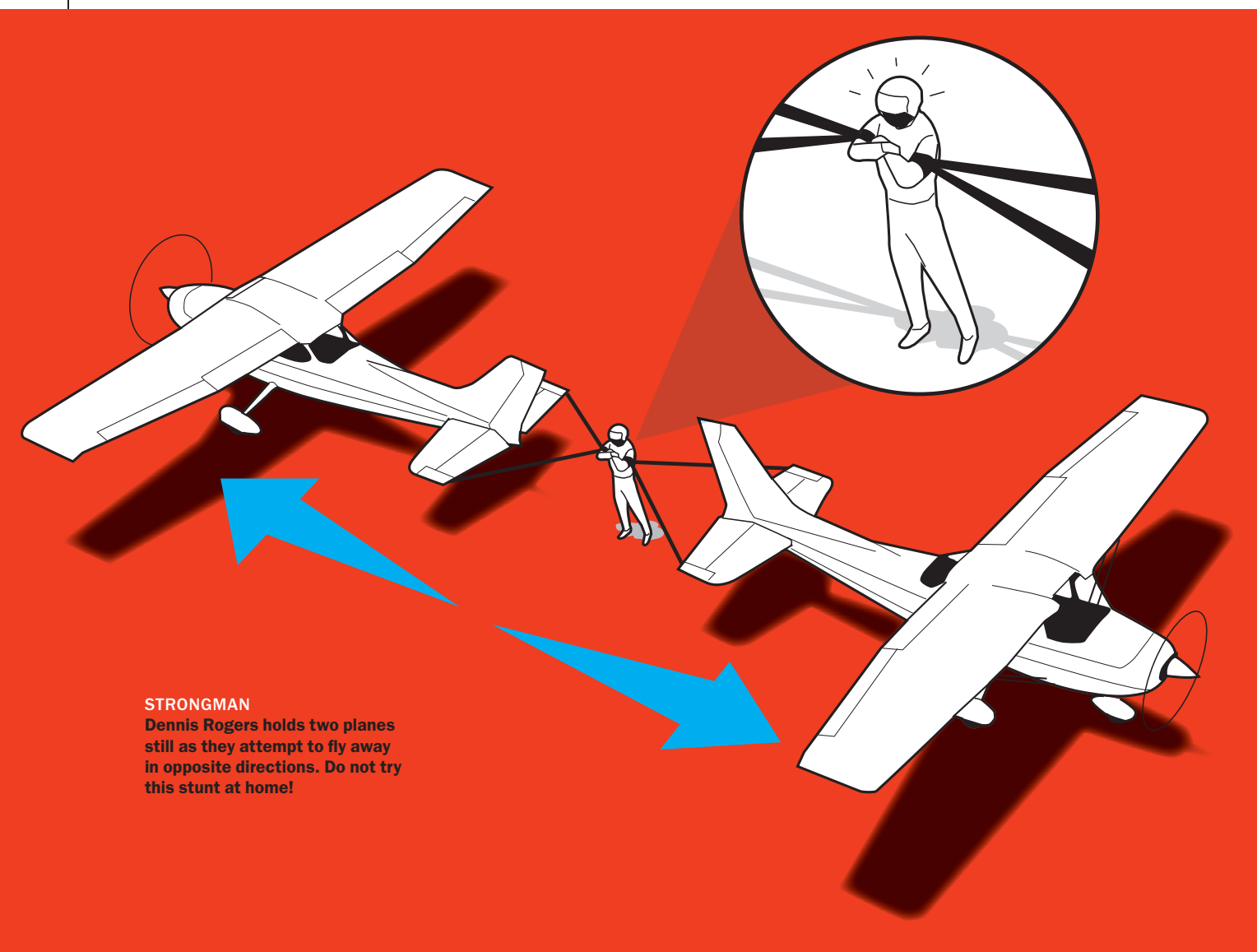
NO BRAIN, No Pain

By Stephen L. Macknik and Susana Martinez-Conde

Pain is an emotion



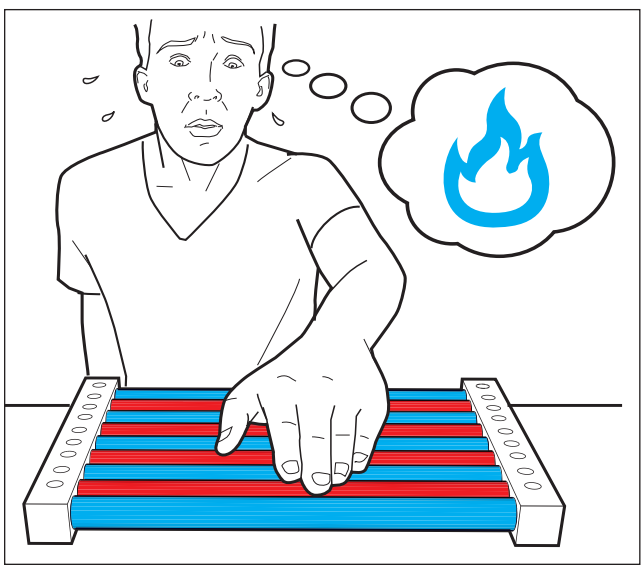
STRONGMAN
Dennis Rogers holds two planes still as they attempt to fly away in opposite directions. Do not try this stunt at home!

We are more often frightened than hurt; and we suffer more from imagination than from reality.

—Lucius Annaeus Seneca

DENNIS ROGERS is an unassuming guy. He's on the short side. And though muscular, he doesn't come across as the kind of towering Venice Beach, muscle-bound Arnold that you might expect from someone billed as the World's Strongest Man. Rather he has the kind of avuncular intensity you find in a great automobile mechanic—a mechanic who happens to be able to lift an engine with one hand while using the fingertips of the other hand to wrench the spark plugs out. Like it's nothing. Rogers, who has been known to keep two U.S. Air Force fighter planes from blasting away in opposite directions by holding them back with his bare hands, performed at the most recent Gathering 4 Gardner—a conference that celebrates the interests of one of *Scientific American*'s greatest columnists, the late mathemagician Martin Gardner. We asked Rogers about the source of his incredible powers after the show, and we were surprised to learn that he did not know. Bill Amonette of the University of Houston–Clear Lake found that Rogers could recruit an abnormally high number of muscle fibers. But was this ability because of a freak genetic mutation? Another possibility, which Rogers thinks is

What if, instead of from **superpowered muscles**, his abilities arise because he can withstand more muscular pain?



ILLUSTRATIONS BY JASON LEE

PAIN IS RELATIVE

Our colleague at the Barrow Neurological Institute, Arthur "Bud" Craig, is a pain neuroscientist who discovered the neural mechanisms underlying the terrifying "thermal grill illusion," in which no damage occurs, but it feels as if it does. Think of it as waterboarding wired directly into your pain system. The device consists of a grill in which every odd horizontal tube is cold (not painful but cold), and every even tube is hot (not painful but very warm). When a subject's hand rests simultaneously on both sets of tubes (cold plus hot), excruciating pain results. This is an illusion; the hand is not damaged, and its actual temperature remains unchanged because the cold and hot tubes cancel out each other thermodynamically. The effect occurs in part because signals from the hand's heat-burn sensors interfere with those from the cold-freeze sensors, creating an imbalanced and painful sensation of burning cold within the brain. But by themselves, the cold and heat are not painful, so the subjective perception of hurt is simply incorrect: no damage, high pain.

Craig has put forward the revolutionary proposal that your brain processes pain like an emotion. If you are tackled while playing the annual family football game before Thanksgiving dinner, it can be fun. But the same tackle, out of the blue, while crossing the park on the way to your promotion review, can hurt like you-know-what: same damage, different pain.

THIS IS GONNA HURT

Henrik Ehrsson, then at the University College London Institute of Neurology, and his colleagues scanned the brains of subjects while threatening a fake hand that appeared attached to the participants. The anterior insula, a brain area that is critical to awareness of your body and, Craig argues, to all emotional awareness, lit up like crazy in brain imaging. The threat of damage, even to a fake appendage, causes brain activity that predicts pain.

When the turning of a dial gave an electric shock **to a virtual character**, observers experienced great stress.

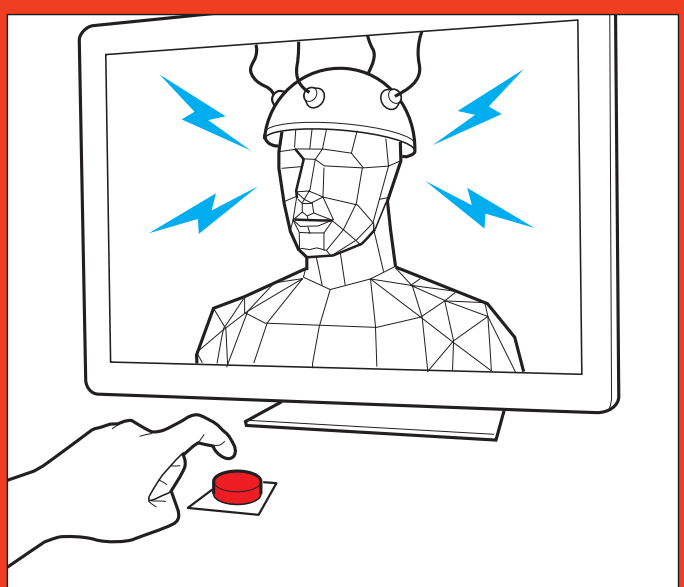
more likely, is the way he processes pain when he strains those muscles.

What if, instead of superpowered muscles, Rogers has a normal—though extremely well exercised—body, and his abilities arise because he can withstand more pain than most mere mortals? He claims that he does feel pain and is actually scared of dentists. In fact, during one stunt in which he held back four souped-up Harley motorbikes with straps, he bit down so hard he split a tooth from top to bottom. Rather than taking his chances at the dentist, he reached into his mouth, clamped his viselike fingertips onto the broken tooth, and extracted it, root and all.

Rogers reasons that, unlike in the dentist's office—where he has no control over the pain that is inflicted on him—he has direct executive control over pain that he inflicts on himself. "I know it's coming, I have an idea of what to expect and I can decide to ignore it," he says. Confronted with severe pain, most people fear that they will damage their body permanently if they persist, so they stop well before they are in real danger, Rogers explains. He does not stop and only rarely gets seriously hurt.

Maybe Rogers's muscle cells are normal, and he experiences pain as most of us do but chooses to disregard it when he feels in command. If so, he has become strong not because he was born on a planet with a red sun like Superman or was trained in the Danger Room of Charles Xavier's School for Gifted Youngsters like an X-Man but because, when he has a job to do, he *doesn't care* that it hurts.

An illusion is a perception that does not match the physical reality. Is pain, then, as with illusions, a mind construct that some people can decide to turn off? As you will see in the studies that follow, pain varies as a function of mood, attentiveness and circumstances, lending support to the theory that pain is an emotion. These studies show that empathy also extends to pain, just as it does to other emotions, even when the victims are fake strangers. The research also indicates that people can experience pain for the wrong reasons or fail to experience it when it would be very reasonable to do so. Moreover, when pain is disconnected from the physical reality, it is an illusion, too.



HURTS ME MORE THAN YOU

Brothers Elliot and Michael motivated their sister, Gertie, in the movie *E.T. the Extra-Terrestrial* by twisting her doll's arm behind its back until Gertie submitted. Why did she care? Two research groups have explored this question recently, both with computer-generated characters and with toy robots. Mel Slater and his colleagues at University College London had subjects turn a dial at the command of an authority figure. The turning of the dial gave an electric shock to a virtual character, who appeared to react in pain. The experimental subjects experienced great stress from inflicting this fictional pain.

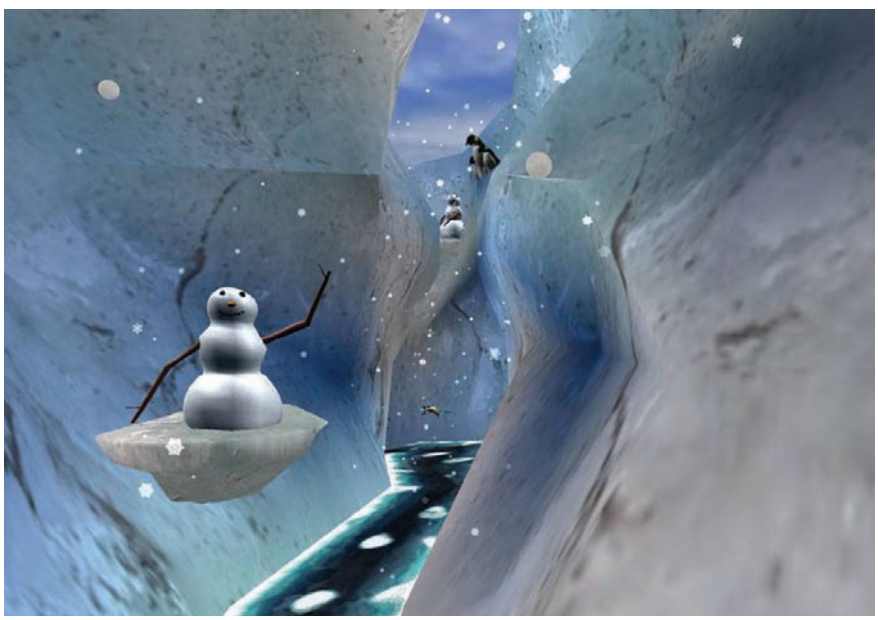
Astrid Rosenthal-von der Pütten and her group at the University of Duisburg-Essen in Germany scanned people's brains as they watched movies of toy robot dinosaurs being mistreated by a human actor. Scientists found significant activity in the limbic areas of the brain, which presumably underlie the feeling of empathy. The same areas lit up even more when research subjects watched movies of humans being abused.

RUBBED THE WRONG WAY

Rogers has had his fair share of close scrapes. Here is the aftermath of a stunt in which a strap holding four straining motorcycles slipped and took the strongman's epidermal layer with it. Rogers was immediately aware of the damage but shrugged it off as too minor to worry about until after the show.

ILLUSION DIMINISHES PAIN

Severe burn victims must have their healing skin pulled and prodded daily to keep it from shrinking like plastic wrap, thus maximizing their mobility. Hunter Hoffman, David Patterson and Sam Sharar of the University of Washington developed a virtual-reality game called Snow World, in which patients in burn units who are undergoing such painful treatments are distracted as they shoot Frosty and his penguin minions with a snowball BB gun. Virtual immersion in the frozen environment reportedly works better than morphine at counteracting the pain: massive damage, low pain.



COURTESY OF DENNIS ROGERS (*top*); IMAGE COURTESY OF ARI HOLLANDER AND HOWARD ROSE; COPYRIGHT HUNTER HOFFMAN *University of Washington www.vrpain.com* (*bottom*)

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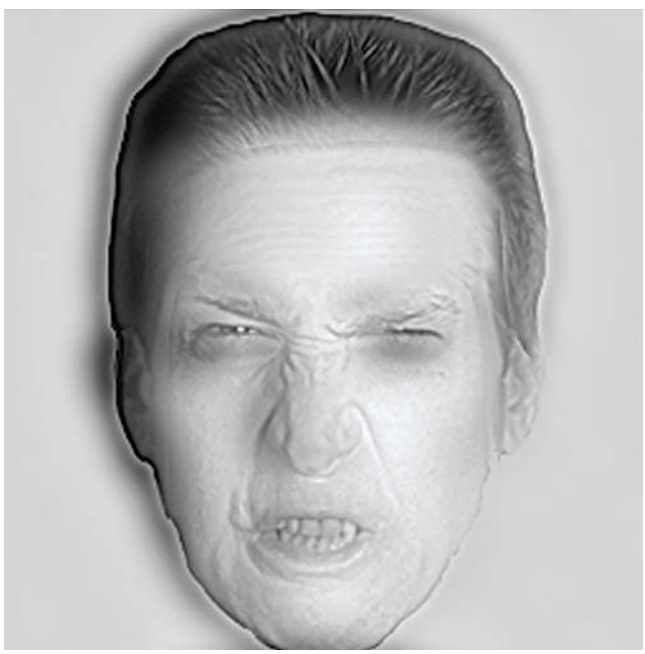
WHAT'S IN A Face?

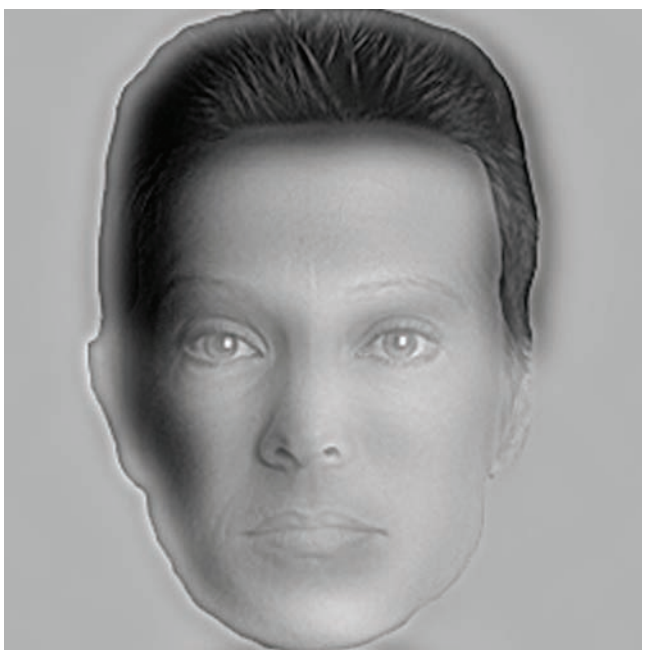
By Susana Martinez-Conde and Stephen L. Macknik

The human brain is good at identifying faces, but illusions can fool our "face sense"

Our brains are exquisitely tuned to perceive, recognize and remember faces. We can easily find a friend's face among dozens or hundreds of unfamiliar faces in a busy street. We look at one another's facial expressions for signs of appreciation and disapproval, love and contempt. And even after we have corresponded or spoken on the phone with somebody for a long time, we are often relieved when we are able to meet him or her in person and are able to put "a face to the name."

The neurons responsible for our refined "face sense" lie in a brain region called the fusiform gyrus. Trauma or lesions to this brain area result in a rare neurological condition called prosopagnosia, or face blindness. Prosopagnostics fail to identify celebrities, close relatives and even themselves in the mirror. But even those of us with normal face-recognition skills are subject to many illusions and biases in face perception.



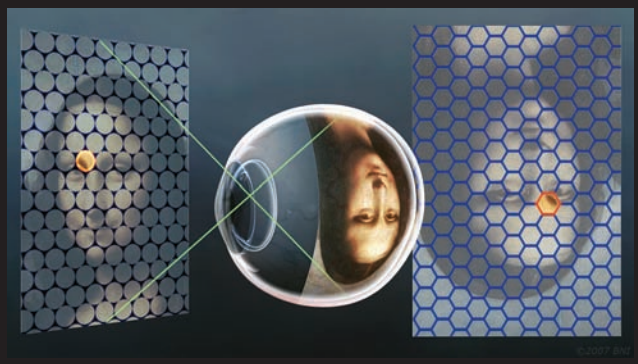


COURTESY OF AUDE OLIVA *M.I.T.* AND PHILIPPE G. SCHYNS *University of Glasgow*

DR. ANGRY AND MR. CALM

Vision scientists Aude Oliva of the Massachusetts Institute of Technology and Phillippe G. Schyns of the University of Glasgow in Scotland created this illusion by producing hybrids of two images. The left picture shows Dr. Angry, and the picture on the right is Mr. Calm. But if you step away from this page, you will see that appearances can be deceiving. Nice Mr. Calm becomes Dr. Angry, and nasty Dr. Angry turns out to be a pretty decent fellow after all.

Fine details become blurred at a distance, leaving you with only the overall shapes and shadings of the images: what vision scientists refer to as the low-spatial-frequency content of an image. When you move closer, the images are once again dominated by their fine details, which are referred to as high spatial frequencies. The illusion works because the face on the left is composed of a high-spatial-frequency angry face combined with a calm face in low spatial frequencies. The right face is exactly the opposite: a low-spatial-frequency angry face with a high-spatial-frequency calm face. When the images are blurred (by stepping away), the hidden layers of the hybrid are revealed.



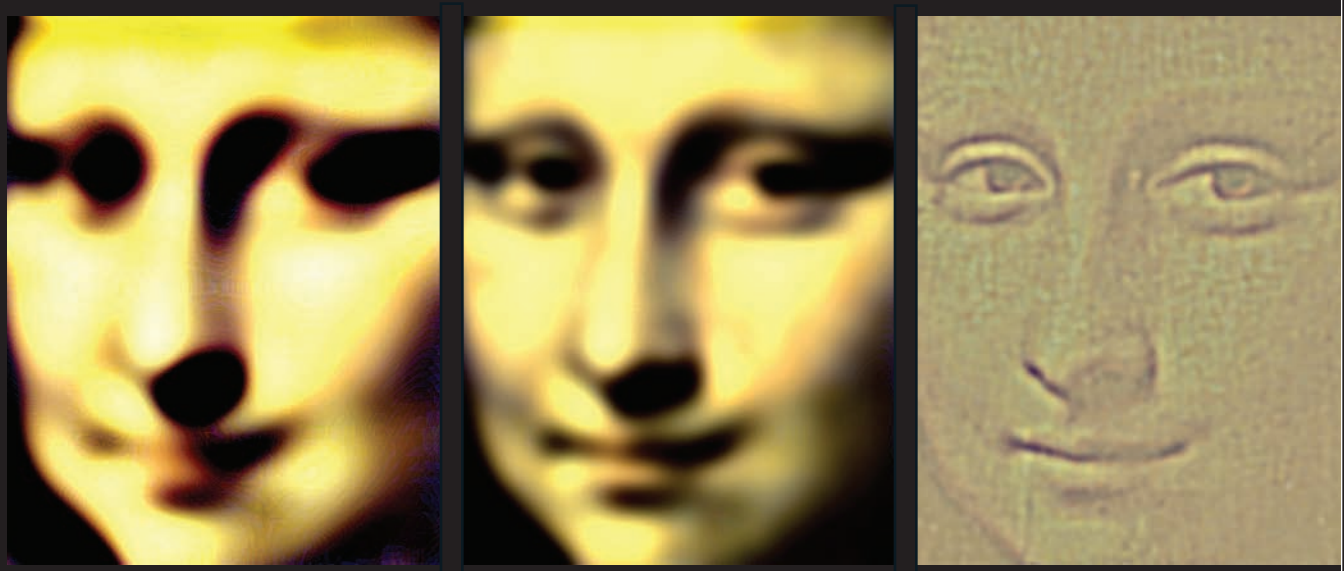
"MONA LISA" SMILE

Mona Lisa's captivating smile (*left*) is perhaps the most renowned art mystery of all time. Margaret S. Livingstone, a neurobiologist at Harvard Medical School, showed that Mona Lisa's smile appears and disappears owing to different visual processes used by the brain to perceive information in the center versus the periphery of our vision.

Look directly at Mona Lisa's lips and notice that her smile is very subtle, virtually absent. Now look at her eyes or at the part in her hair, while paying attention to her mouth. Her smile is much wider. The movement of our eyes as we gaze around Mona Lisa's face makes her smile come alive, flickering on and off as our perception of it changes.

The center and periphery of the visual field have this differential effect on perception because the neurons at the center of our vision see a very small portion of the world, giving us high-resolution vision. Conversely, the neurons in the periphery see much larger pieces of the visual scene and thus have lower resolution.

This is what happens in the eye while viewing Mona Lisa: the eye focuses light that is reflected from the painting onto the retina, upside down and backward (*above*). Adjacent photoreceptors within the retina are activated by adjacent points of light reflected from the painting.

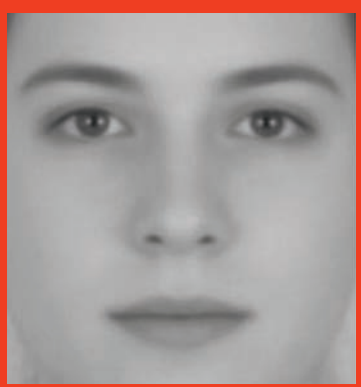


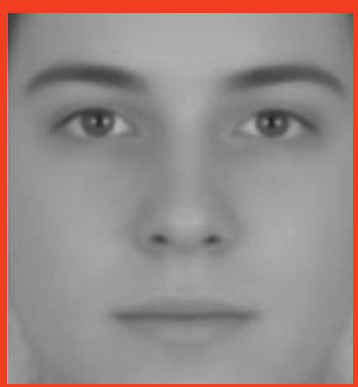
THE DA VINCI CODE OF PERCEPTION

Mona Lisa's smile can be explained by the fact that images are blurred in the periphery of our vision, so that her smile is only seen when blurred. Livingstone solved this mystery by simulating how the visual system sees Mona Lisa's smile in the far periphery, the near periphery, and the center of our gaze (*above, left to right*). The simulation was done in Adobe Photoshop by simply blurring and deblurring the painting to simulate the change in resolution from the center of vision to the far periphery. The smile appears on the left and center panels (far and near visual periphery) but is gone on the right panel (center of gaze). The effect is similar to the hybrid images of Dr. Angry and Mr. Calm and is likewise explained by the fact that different retinal neurons are tuned to different spatial frequencies. In a sense, Leonardo da Vinci painted the Mona Lisa as a hybrid, with a happy Mona Lisa superimposed on a sad one, each having different spatial-frequency content.

MONA LISA (C. 1503–1506, OIL ON PANEL), BY LEONARDO DA VINCI (1452–1519)/LOUVRE, PARIS/GIRAUDON/THE BRIDGEMAN ART LIBRARY (*top left*); COURTESY OF BARROW NEUROLOGICAL INSTITUTE (*top right*); COURTESY OF MARGARET S. LIVINGSTONE *Harvard Medical School (bottom)*

HONEST ABE
Surrealist painter Salvador Dalí also experimented with combining high- and low-spatial-frequency content in a single image (*right*). The title of the painting says it all: *Gala Contemplating the Mediterranean Sea, which at Twenty Meters Becomes the Portrait of Abraham Lincoln (Homage to Rothko)*. The finer details of the painting, such as the edges of the colored blocks, blur when you view the painting from a distance or squint your eyes—and you can then see the low-spatial-frequency shapes and shading that make up Lincoln's face.





ILLUSION OF SEX
This illusion, created by psychologist Richard Russell, won third prize in the 2009 Best Illusion of the Year Contest. The side-by-side faces are perceived as female (*left*) and male (*right*). Yet both are versions of the same androgynous face (see http://illusionoftheyear.com/2009/the-illusion-of-sex). The two images are identical, except that the contrast between the eyes and mouth and the rest of the face is higher for the face on the left than for the face on the right.

This illusion shows that contrast is an important cue for determining the sex of a face, with low-contrast faces appearing male and high-contrast faces appearing female. It may also explain why females in many cultures darken their eyes and mouths with cosmetics: a made-up face looks more feminine than a fresh face.

FELINE FACE
Cat Woman (*right*), created at Oliva's M.I.T. laboratory, is a hybrid image of a woman (*left*) and a cat. At close range, *Cat Woman* has a cat's face. But at a distance, coarse features obscure the whiskers, fur texture and other details. Simply superimposing a transparent cat's face on a woman's face would not produce the same effect; this illusion works only by combining two images that differ in their spatial detail—one fine and one coarse.

© SALVADOR DALÍ, FUNDACIÓ GALA-SALVADOR DALÍ, ARTISTS RIGHTS SOCIETY, NEW YORK, 2013, AND *GALA CONTEMPLATING THE MEDITERRANEAN SEA WHICH AT EIGHTEEN METRES BECOMES THE PORTRAIT OF ABRAHAM LINCOLN (HOMAGE TO ROTHKO)* (1976, OIL ON PHOTOGRAPHIC PAPER), BY SALVADOR DALÍ (1904–1989)/MUSEO DALÍ, FIGUERES, SPAIN/INDEX/THE BRIDGEMAN ART LIBRARY (*top*); COURTESY OF RICHARD RUSSELL *Gettysburg College* (*middle*); COURTESY OF AUDE OLIVA (*bottom*)

MARGARET THATCHER ILLUSION

This illusion by vision scientist Peter Thompson of the University of York in England was critical to our understanding of face perception. When the illusion was discovered in 1980, scientists already knew that faces were difficult to recognize upside down. But the assumption was that because the brain always sees faces right side up, the face-recognition cells were optimized for right-side-up faces. This assumption was partially true, but the Margaret Thatcher illusion went further to show that the brain does not simply process and store representations of whole faces; rather it recognizes representations of individual facial features such as the mouth and eyes.

The top and bottom row of Thatcher images are identical to each other but flipped vertically. The top row looks like two upside-down Thatchers, no problem there. But the bottom row looks like a Thatcher on the left and a horrible mutant on the right. The reason is that whereas the left column depicts normal faces (although the upper face is upside down), the right column shows Frankenstein-ish composites of Thatcher with only the eyes and mouths flipped vertically. The Thatcher at the upper right does not freak you out, because the eyes and mouth are right side up (although the overall face is upside down), and your face-perception neurons therefore see them as "normal" (even though they do not match the rest of the face).

The bottom right image is creepy because the eyes and mouth are upside down and thus all wrong, despite the fact that the face as a whole is right side up. Research at Harvard by neuroscientists Winrich Freiwald, Doris Tsao and Livingstone has found neurons in the brain that respond to specific face features such as mouths and eyes, confirming the predictions that were made from this illusion several decades earlier.

TONY BLAIR ILLUSION

Vision scientist Stuart Anstis of the University of California, San Diego, created this illusion in 2005 to celebrate the 25th anniversary of the Thatcher illusion. Anstis reasoned that if face-detecting neurons prefer right-side-up facial features, they should also be selective for other evolutionarily stable aspects of faces. He tested this idea by comparing positive and negative images of Tony Blair. Because we have evolved to see faces only in positive contrast, it follows that the perception of individual facial features should fail if shown in negative. As with the Thatcher illusion, showing the whole face in negative (*top left*) makes it less recognizable than the normal face (*bottom left*). Using positive images of the mouth and eyes overlaid on a negative face does not look particularly grotesque either (*top right*). But a positive image of Blair with a negative mouth and eyes (*bottom right*) is just as horrid as the upside-down mouth and eyes in the right-side-up Thatcher.

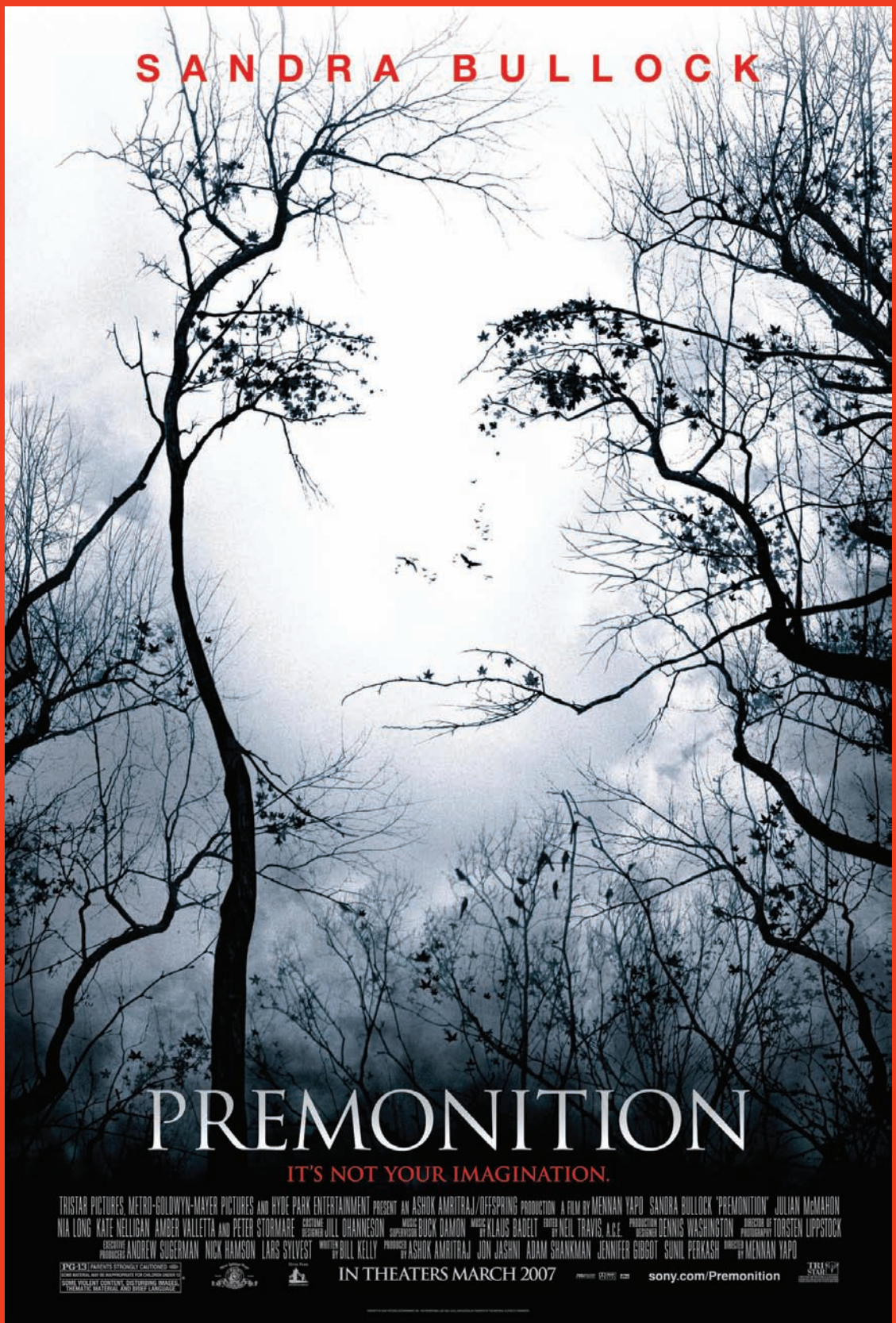
COURTESY OF PETER THOMPSON *University of York*, FROM "MARGARET THATCHER: NEW ILLUSION," BY PETER THOMPSON, IN *PERCEPTION*, VOL. 9, NO. 4, 1980. REPRINTED WITH PERMISSION FROM PION LTD, LONDON (WWW.ENVPLAN.COM) (*top*); COURTESY OF STUART ANSTIS *U.C.S.D.* (*bottom*)

MOONEY FACES

Our nervous systems are hardwired to detect and process faces rapidly and efficiently, even with scarce details. Pictures such as the ones shown above are often referred to as Mooney faces, after cognitive psychologist Craig Mooney, who used similar images in his research on perception. Mooney faces illustrate how little visual information it actually takes to "see" a face.

The artist who created the movie poster for *Premonition* understood this phenomenon (*opposite page*). The tree branches, leaves and birds in the poster form only the barest outline of actress Sandra Bullock's face. Our brains fill in the gaps and construct a finished face from sparse visual content.

AARON SCHURGER


SANDRA BULLOCK
PREMONITION
IT'S NOT YOUR IMAGINATION.
TRISTAR PICTURES, METRO-GOLDWYN-MAYER PICTURES AND HYDE PARK ENTERTAINMENT PRESENT AN ASHOK AMRITRAJ/OFFSPRING PRODUCTION A FILM BY MENNAN YAPO SANDRA BULLOCK "PREMONITION" JULIAN McMAHON
NIA LONG KATE NELLIGAN AMBER VALLETTA AND PETER STORMARE COSTUME DESIGNER JILL OHANNESON MUSIC SUPERVISION BUCK DAMON MUSIC BY KLAUS BADELT EDITED BY NEIL TRAVIS, A.C.E. PRODUCTION DESIGNER DENNIS WASHINGTON DIRECTOR OF PHOTOGRAPHY TORSTEN LIPPSTOCK
EXECUTIVE PRODUCERS ANDREW SUGERMAN NICK HAMSON LARS SYLVEST WRITTEN BY BILL KELLY PRODUCED BY ASHOK AMRITRAJ JON JASHNI ADAM SHANKMAN JENNIFER GIBGOT SUNIL PERKASH DIRECTED BY MENNAN YAPO
PG-13 PARENTS STRONGLY CAUTIONED
IN THEATERS MARCH 2007
sony.com/Premonition

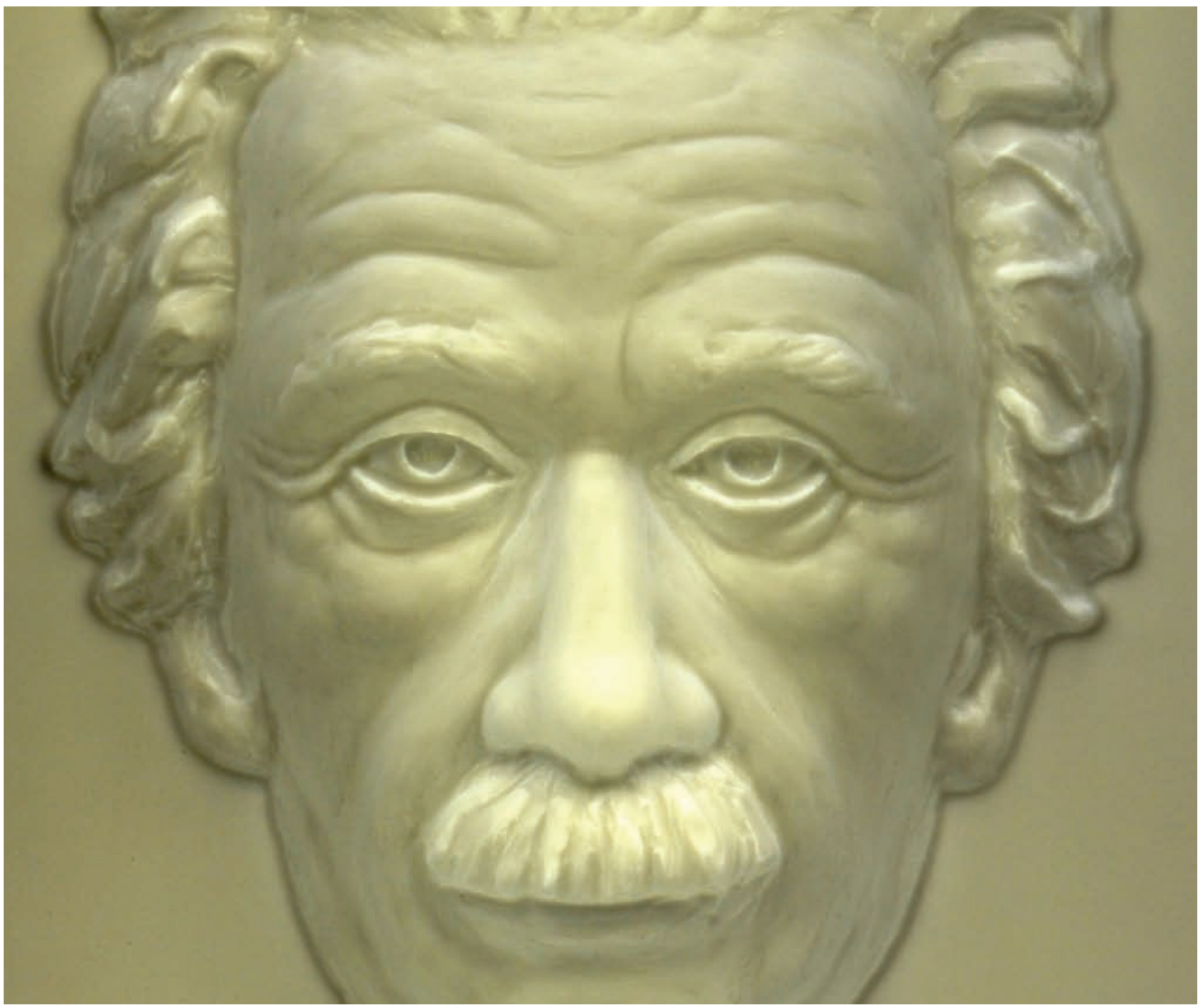
TRI-STAR/THE KOBAL COLLECTION AT ART RESOURCE, NY

HOLLOW MASK ILLUSION

This hollow mask created by sculptor Bryan Parkes gives the eerie impression that Albert Einstein's face is following you as you move around the room (*below*). The mask is placed in front of a window, with its open back facing toward you, so that sunlight illuminates the plastic face. Although the mask is concave, your brain assumes that all faces are convex. While a convex face would look in only one direction, Einstein's hollow face seems to look forward when the viewer is directly ahead, but at an angle when the viewer moves sideways. In another demonstration of this well-known illusion, when a hollow mask rotates on a turntable, it appears to turn opposite to the actual direction of the turntable.

Vision researcher Thomas Papathomas of Rutgers University created an interesting variation on this illusion by attaching three-dimensional eyeballs and a nose ring to a hollow mask. As shown in these three frames from a movie of the rotating mask, the eyeballs and nose ring appear to rotate in the opposite direction to that of the mask (*above*).

This illusion won third prize in the 2008 Best Illusion of the Year Contest. You can view the movie at http://illusionoftheyear.com/2008/rolling-eyes-on-a-hollow-mask



COURTESY OF THOMAS PAPATHOMAS *Rutgers University (top)*; COURTESY OF WWW.GRAND-ILLUSIONS.COM *(bottom)*

RACE FACE ILLUSION

While viewing composites of racially black (*left*) and white (*right*) faces that reflect exactly the same amount of light, two psychologists noticed an interesting illusion: the white face appears lighter. Daniel T. Levin of Vanderbilt University, working with Mahzarin R. Banaji of Harvard University, proposed that the distortion occurs because abstract social expectations about skin tone influence our perception of faces.

SURROUNDED BY FACES

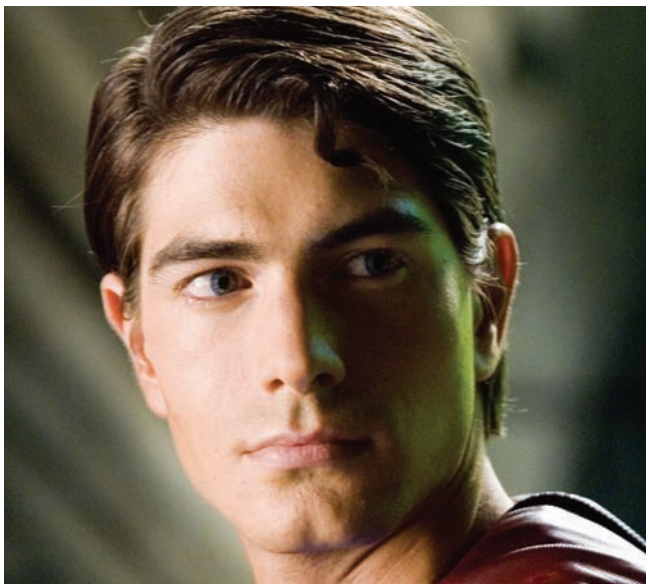
Because our brains are so good at detecting faces, we sometimes see them where they do not exist. Were you ever scared as a child by strange faces popping up from an abstract wallpaper design or formed by shadows in the semidarkness of your bedroom? Ever noticed that cars seem to have faces, with the headlights as eyes and the grilles as mouths? These effects result from the face-recognition circuits of our brains, which are constantly trying to find a face in the crowd.

COURTESY OF DANIEL T. LEVIN *Vanderbilt University (top)*; TSUNEO YAMASHITA *Getty Images (bottom)*

THE MANE DIFFERENCE

Visual illusions showcasing politicians are all the rage. At first sight it looks like Al Gore standing behind Bill Clinton, but notice that Gore is really a doppelgänger Clinton, only with Gore's gorgeous head of hair (*left*). A set of face features (Clinton's) mixed with a different set of features (Gore's hair) isn't easily recognized as being misplaced.

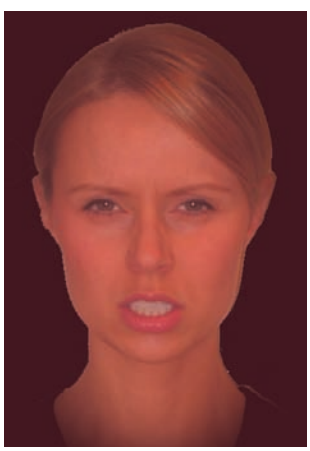
Superman relies on the same illusion to protect his identity: thanks to a pair of glasses, a change of clothes and a different hairstyle, nobody in Metropolis realizes that he and Clark Kent are the same person (*below*).

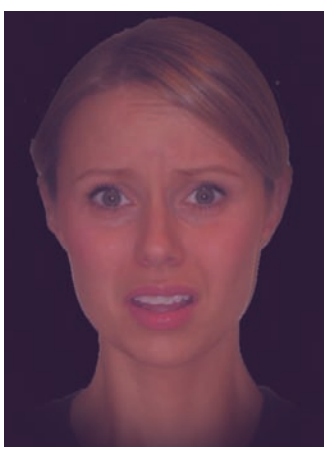


EMOTION ADAPTATION

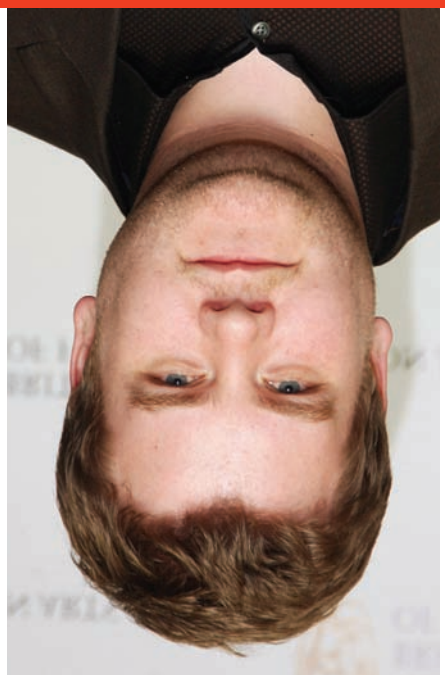
Gaze at the angry face (*left*) for about 30 seconds while looking around the face from the eyes to the mouth, to the nose, back to the eyes, and so on. Then look at the center face. It looks scared, right? Now look at the scared face (*right*) for 30 seconds and then look at the center face again. This time it is angry! In reality, the center face is a 50–50 blend of an angry and a scared face.

Created by Andrea Butler and her colleagues at the University of British Columbia, this illusion shows that our visual-processing system adapts to an unchanging facial expression by temporarily becoming less responsive to it. As a result, the other facial expression dominates when you view the blend. This adaptation occurs in higher-level brain circuits, rather than in the retina, because the illusion works even if you view the left or right image with one eye only and then look at the center image with your other (unadapted) eye.





COURTESY OF PAWAN SINHA AND TOMASO POGGIO *M.I.T.* (*top*); WARNER BROS./DC COMICS/THE KOBAL COLLECTION AT ART RESOURCE, NY (*middle*); COURTESY OF JASON BARTON *University of British Columbia*; FROM "FACTORS CONTRIBUTING TO THE ADAPTATION AFTEREFFECTS OF FACIAL EXPRESSION," BY A. BUTLER ET AL., IN *BRAIN RESEARCH*, VOL. 1191; JANUARY 29, 2008. WITH PERMISSION FROM ELSEVIER (*bottom*)



FAT FACE THIN ILLUSION

Peter Thompson, who discovered the Thatcher illusion, has now identified a new illusion that he calls the "fat face thin illusion." In this example of the illusion, the photographs are identical, but the upside-down face appears strikingly slimmer than the right-side-up version.

One possible explanation is that it is easier for the brain to recognize distinctive facial features, such as chubby cheeks, when they are viewed in the normal upright position. But that does not explain why thin faces don't look fatter—or thinner still—when viewed upside down.

This illusion competed as a top-10 finalist in the 2010 Best Illusion of the Year Contest.

FOCUS ON FACES

Facial expressions play a key role in our everyday social interactions. Even when watching movies or looking at photographs, we spend most of our time looking at the faces they portray. Our intense focus on faces is at the expense of other potentially interesting information, however. Take a quick look at this woman and child. Their smiling faces suggest they are having a good time. But is that it? Look more closely, and you may notice that the girl has an extra finger on her right hand: something that you probably missed at first because your attention was fixed on the faces.

DAN KITWOOD *Getty Images (top)*; PHOTOCOMPOSITION BY SMITHA ALAMPUR; THOMAS POLEN *iStockphoto (bottom)*

THE Eyes Have It

By Susana Martinez-Conde and Stephen L. Macknik

Eye gaze is critically important to social primates such as humans. Maybe that is why illusions involving eyes are so compelling

The eyes are the window to the soul. That is why we ask people to look us in the eye and tell us the truth. Or why we get worried when someone gives us the evil eye or has a wandering eye. Our language is full of expressions that refer to where people are looking—particularly if they happen to be looking in our direction.

As social primates, humans are keenly interested in determining the direction of gaze of other humans. It is important for evaluating their intentions and critical for forming bonds and negotiating relationships. Lovers stare for long stretches into each other's eyes, and infants focus intently on the eyes of their parents. Even very young babies look at simple representations of faces for longer than they look at similar cartoonish faces in which the eyes and other features have been scrambled.

In this article, we investigate a series of illusions that take advantage of the way the brain processes eyes and gaze. It turns out that it is fairly easy to trick us into thinking that someone is looking somewhere else.

COURTESY OF ROB JENKINS *University of York*

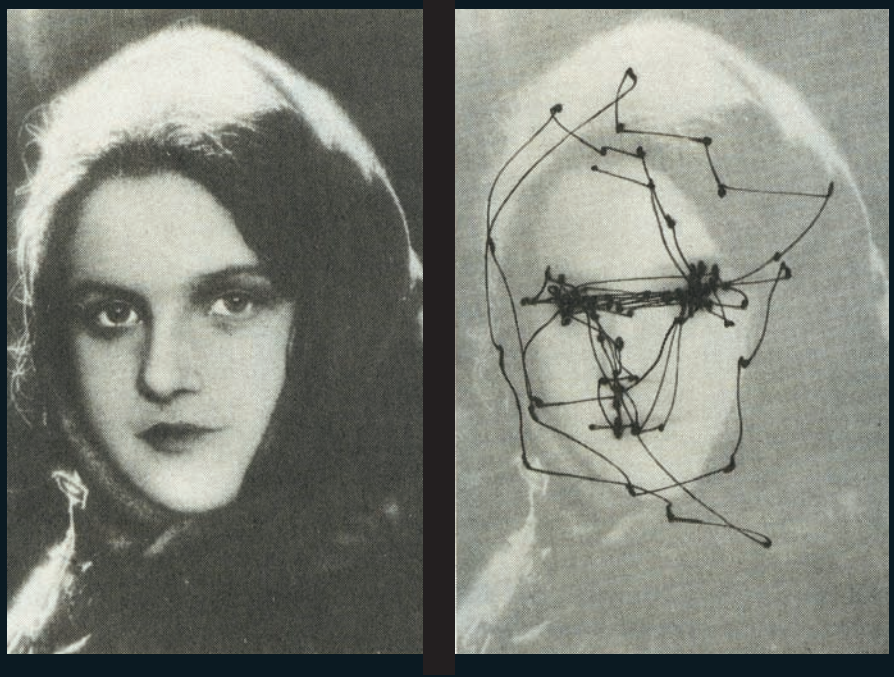
GHOSTLY GAZES

Not knowing where a person is looking makes us uneasy. For this reason, it can be awkward to converse with somebody who is wearing dark sunglasses. And it is why someone might wear dark sunglasses to look "mysterious."

A recently identified visual illusion takes advantage of the unsettling effect of uncertainty in gaze direction. The "ghostly gaze" illusion, created by Rob Jenkins, now at the University of York in England, was awarded second prize in the 2008 Best Illusion of the Year Contest, held in Naples, Fla. In this illusion (*left* and *center*), twin sisters appear to look at each other when seen from afar. But as you approach them, you realize that the sisters are looking directly at you!

The illusion is a hybrid image that combines two pictures of the same woman. The overlapping photos differ in two important ways: their spatial detail (fine or coarse) and their direction of gaze (sideways or straight ahead). The images that look toward each other contain only coarse features, whereas the ones that look straight ahead are made up of sharp details. When you approach the pictures, you are able to see all the fine detail, and so the sisters seem to look straight ahead. But when you move away, the gross detail dominates, and the sisters appear to look into each other's eyes. See an interactive demo at http://illusionofthe year.com/2008/ghostly-gaze

In another example of a hybrid image (*right*), a ghostly face appears to look to the left when you hold the page at normal reading distance. Step back a few meters, however, and she will look to the right.



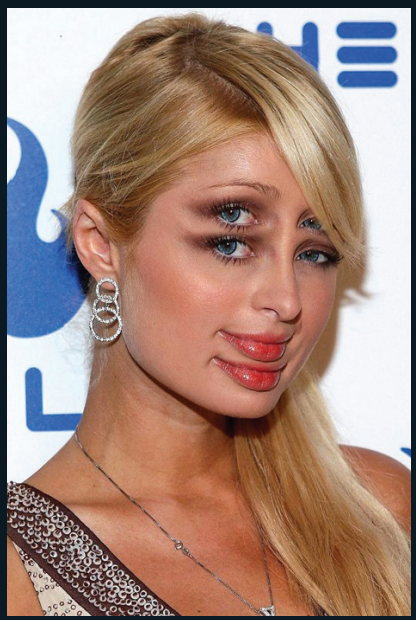
FOCUS ON THE EYES

About 50 years ago Russian psychologist Alfred L. Yarbus tracked the eye movements of volunteers as they viewed photographs of human faces and found that observers were primarily interested in the eyes shown in the portraits. But even though most of us pay close attention to the area of the face around the eyes, we are still forced to take lots of shortcuts when figuring out where someone is looking. These sensory shortcuts are what make us so vulnerable to visual illusions involving gaze.

EINSTEIN'S ALTER EGOS

The ghostly gaze illusion is based on a hybrid-image technique created by Aude Oliva of the Massachusetts Institute of Technology and Philippe G. Schyns of the University of Glasgow in Scotland. In a shocking example of how perceptual interpretation of hybrid images varies with viewing distance, Albert Einstein, seen from up close, becomes Marilyn Monroe (*left*) or Harry Potter (*right*), when seen from a few meters away. For more hybrid images created by the Oliva laboratory, visit the hybrid-image gallery at http://cvcl.mit.edu/hybrid_gallery/gallery.html

FROM "EYE MOVEMENT AND VISION," BY A. L. YARBUS. PLENUM PRESS, 1967. USED WITH PERMISSION FROM SPRINGER SCIENCE+BUSINESS MEDIA B.V. (*top*); COURTESY OF AUDE OLIVA *M.I.T.* (*bottom*)

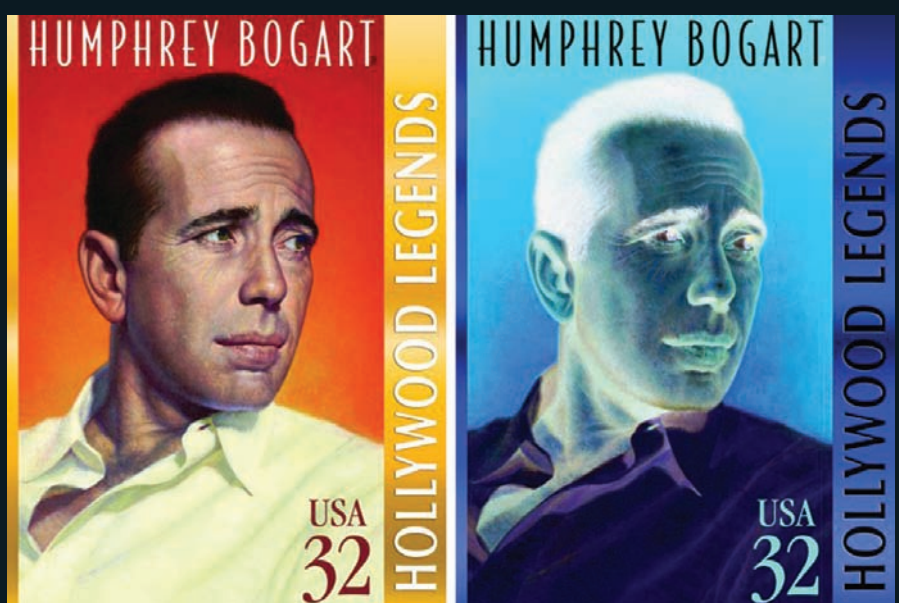


SEEING DOUBLE?

What if you duplicate some of the features of a portrait without overlapping them completely? It is relatively easy to create images in Photoshop in which the eyes and the mouth, but no other facial features, have been doubled. The results are little short of mind-bending: as the brain struggles (and fails) to fuse the doubled-up features, the photograph appears unstable and wobbly, and observers experience something akin to double vision. The neural mechanisms for this illusion may lie within our visual system's specialized circuits for face perception. If you double up the eyes and mouth in a portrait, the neurons in the face-recognition areas of the brain may not be able to process this visual information correctly. Such failure could make the face unsteady and difficult to perceive.

HERE'S LOOKIN' AT YOU, KID

Vision researcher Pawan Sinha of the Massachusetts Institute of Technology shows us with this illusion that our brain has specialized mechanisms for determining gaze direction. In the normal photograph of Humphrey Bogart (*left*), the actor appears to be looking to his left, but in the photo negative (*right*) he appears to be looking in the opposite direction. Yet Bogart's face does not look backward; only the eyes are reversed. Why? The answer is that we have specialized modules in our brain that determine gaze direction by comparing the dark parts of the eyes (the irises and pupils) with the whites. When the face is negative, the whites and irises appear to swap position. Our knowledge that irises are light rather than dark in a negative does not change our perception of this illusion.



COURTESY OF FREAKINGNEWS.COM (*top*); COURTESY OF PAWAN SINHA AND TOMASO POGGIO *M.I.T.* (*bottom*)

COURTESY OF LIBRARY OF CONGRESS, PRINTS & PHOTOGRAPHS DIVISION (*top*); COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University* (*bottom*)

FOLLOW MY FINGER

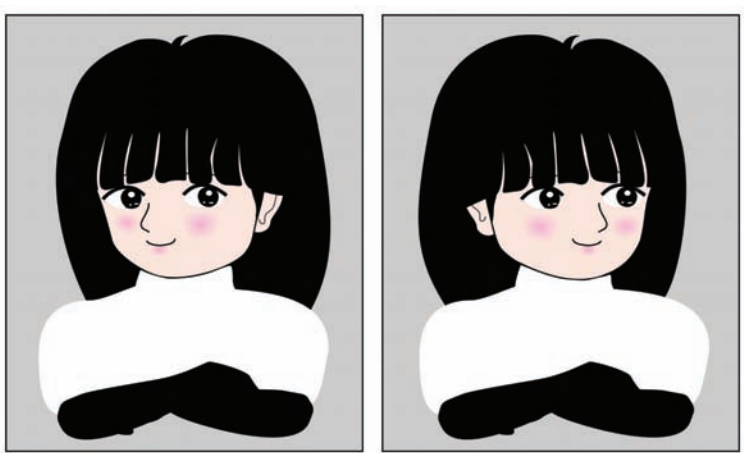
The artists who drew these World War I recruiting posters knew something about eye tracking. No matter how you look at Uncle Sam (*right*) or British Field Marshal Lord Kitchener (*left*), the eyes and finger seem to be pointed directly at you. Today you can experience the same phenomenon in an art museum, where the painted eyes in portraits sometimes seem to follow you around the room.

Such eye tracking is not only a B-movie horror flick cliché but also a powerful illusion that continues to inspire visual science studies. In 2004 vision psychologists Jan Koenderink, Andrea van Doorn and Astrid Kappers, all then at Utrecht University in the Netherlands, along with James Todd of Ohio State University, concluded that, contrary to popular belief, this compelling illusion does not require special artistic abilities on the part of the painter. Surprisingly, all that is required is that the person portrayed looks straight ahead, and the observer's visual system takes care of the rest.

The deceptively simple explanation is that when we look at a real human face or anything else in our three-dimensional physical world, the visual information that specifies near and far points changes with our viewing angle. But when we observe a two-dimensional painting or photograph hanging on the wall or a poster such as the ones above, the visual information that defines near and far points remains unaltered by our viewing angle. The brain interprets this information as if it pertained to a 3-D object, however. That interpretation is what creates the eerie sensation that a portrait's eyes are following you.

CONTEXTUAL CUES

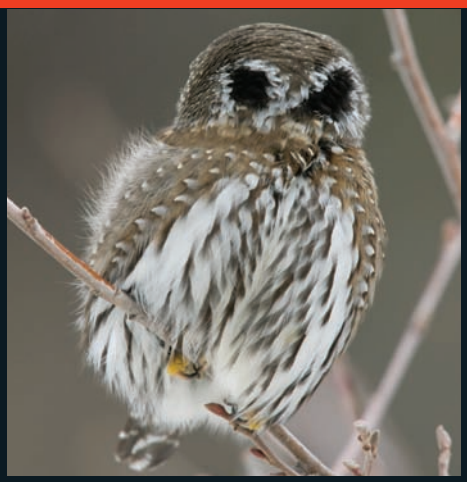
Contextual cues, such as the position of the face and the head, also influence the perceived direction of gaze. In this illusion created by Akiyoshi Kitaoka, a professor of psychology at Ritsumeikan University in Japan, the girl on the left appears to gaze directly at you, whereas the girl on the right appears to be looking to her left. In reality, the eyes of both girls are identical. This illusion was first described in 1824 by British chemist and natural philosopher William Hyde Wollaston, who also discovered the elements palladium and rhodium.



ANIMAL "EYES"

A fascination with eyes is not solely a human trait. Many species of fish, insects and even birds sport false (one could say illusory) eyes on their wings, stalks or even the back of their head. These eye-catching patterns do not necessarily mimic real eyes, but they serve to dissuade, confuse or startle potential predators. Get an eyeful of these animals that sport eyespots (*clockwise from upper left*): an emperor moth with four false eyes, a northern pygmy owl with "eyes" in the back of its head, a butterfly fish with a fake eye that draws attention away from its head, an insect named the eyed click beetle, and a spicebush swallowtail caterpillar.

THOMAS MARENT *Minden Pictures (top)*; DARLYNE A. MURAWSKI *Getty Images (bottom)*



DONALD M. JONES *Minden Pictures (top left)*; DAVID FLEETHAM *Getty Images (top right)*; PAUL E. TESSIER *Getty Images (bottom)*

THE ILLUSIONS OF Love

By Stephen L. Macknik and Susana Martinez-Conde

How do we fool thee?
Let us count the ways that illusions play with our hearts and minds

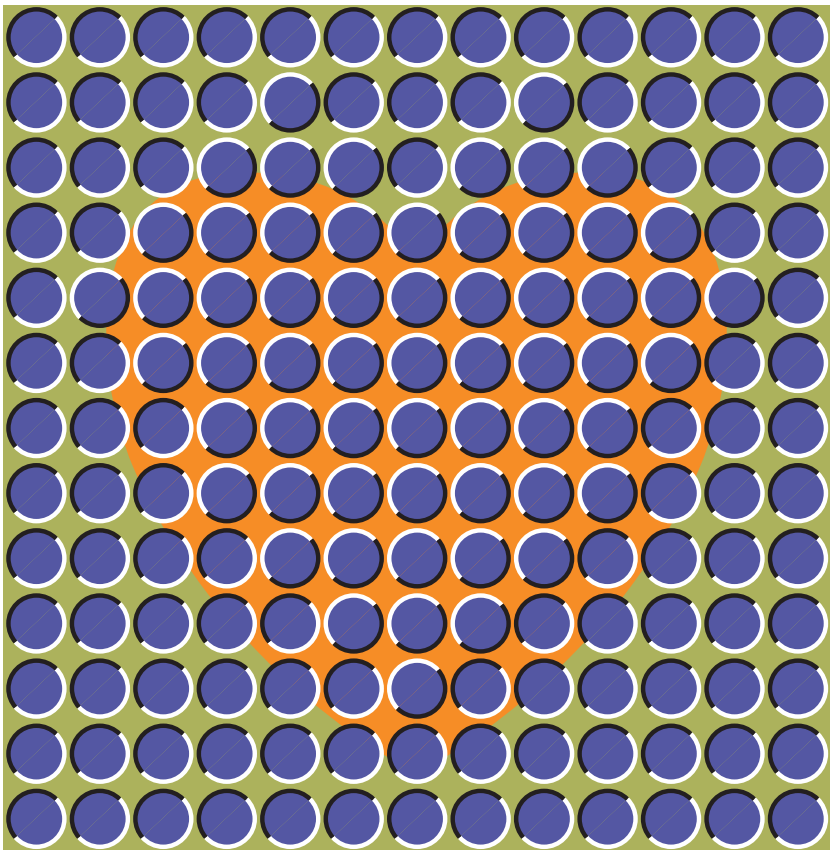
On Valentine's Day, everywhere you look there are heart-shaped balloons, pink greeting cards and candy boxes filled with chocolate. But what is true love? Does it exist? Or is it simply a cognitive illusion, a trick of the mind?

Contrary to the anatomy referenced in all our favorite love songs, love (as with every other emotion we feel) is not rooted in the heart but in the brain. (Unfortunately, Hallmark has no plans to mass-produce arrow-pierced chocolate brains in the near future.) By better understanding how the brain falls in love, we can learn about why the brain can get so obsessed with this powerful emotion. In fact, some scientists even see love as a kind of addiction. For instance, neuroscientist Thomas Insel and his colleagues at Emory University discovered that monogamous pair bonding has its basis in the same brain reward circuits that are responsible for addiction to drugs such as cocaine and heroin. Their study was conducted in the prairie vole, a small rodent that mates for life. But the conclusions are probably true for humans, too, which may explain why it is so hard to break up a long-term romantic relationship. Losing someone you love is like going through withdrawal.

In this article, we feature a number of visual illusions with a romantic motif. We hope that you and your special one will enjoy them. And remember, even if love is an illusion, that doesn't mean it's not meaningful and real (to our brain, anyway).

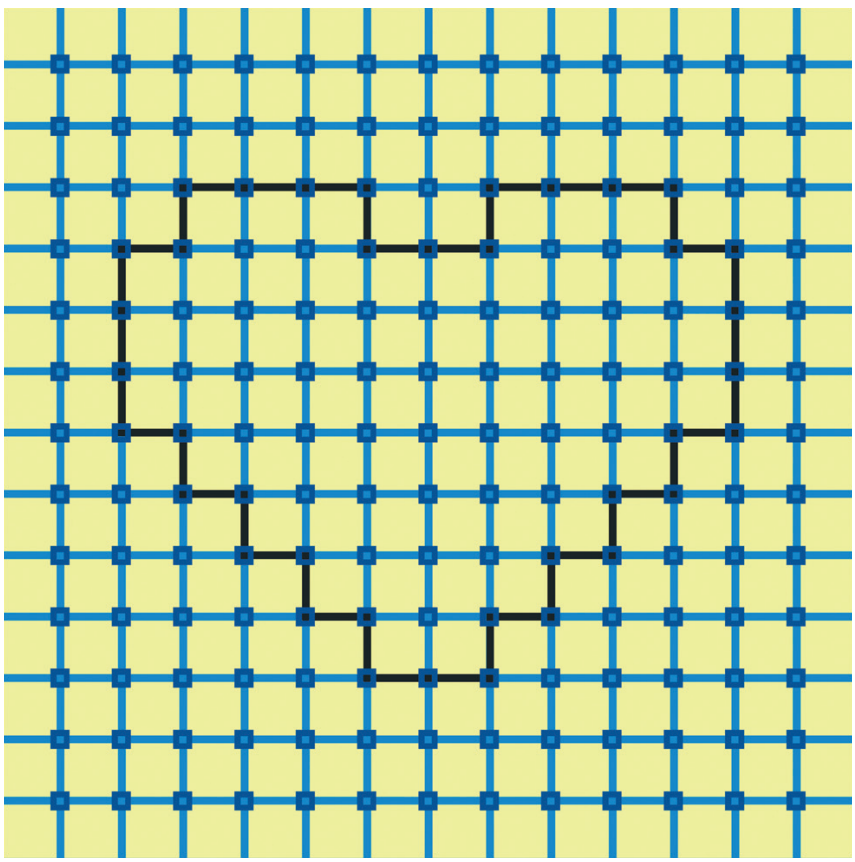
THE SHADOW OF LOVE
Many objects can cast heart-shaped shadows. For example, love can be seen through rose-colored glasses (*left*) or writ large (*right*).

DIMITRI VERVITSIOTIS *Getty Images (left)*; GETTY IMAGES (*right*)



ILLUSIONS THAT MOVE THE HEART

Your wandering eyes pull at your lover's heartstrings. In this illusion, the heart appears to move and even pulsate as you look around the picture. When your eyes move, they shift the retinal images of the black-and-white edges in the pattern, activating the motion-sensitive neurons in your visual cortex. This neural activation leads to the perception of illusory motion. Notice that if you focus your gaze on a single point, the illusory motion slows or stops.



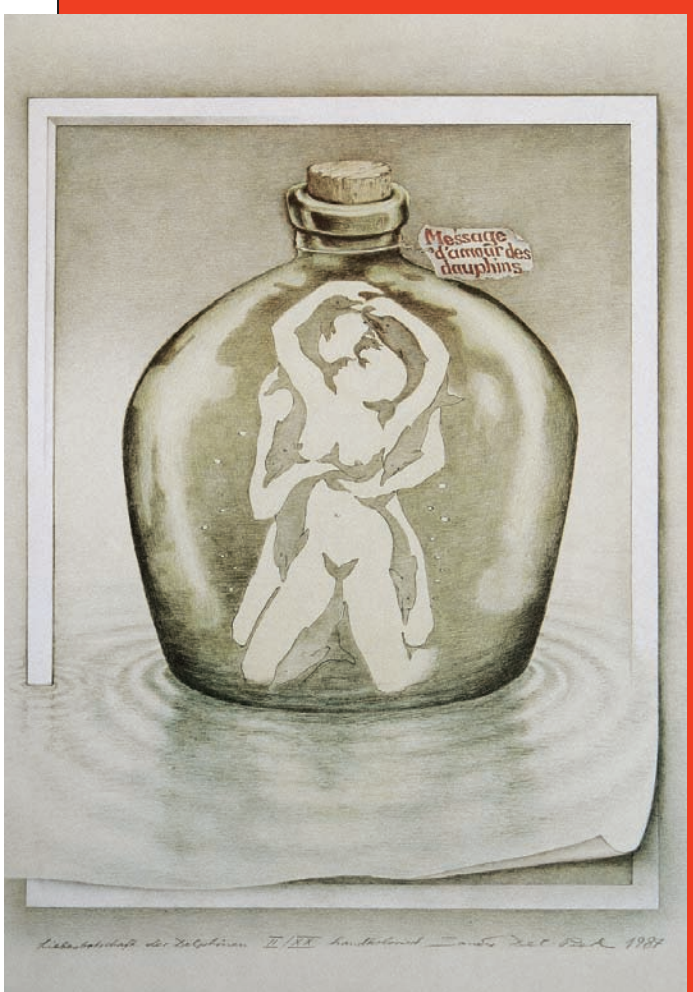
ILLUSORY NEON HEART

The yellow fields inside the heart seem paler than the fields forming the contour of the heart, which appear to be a darker shade of yellow-orange. Right? Wrong. Actually all the yellow fields in the figure are identical. Any differences that you see are all in your mind. This effect is called neon color spreading because it resembles the effect of the light spreading from a neon lamp. The neural underpinnings of this effect are not yet understood.

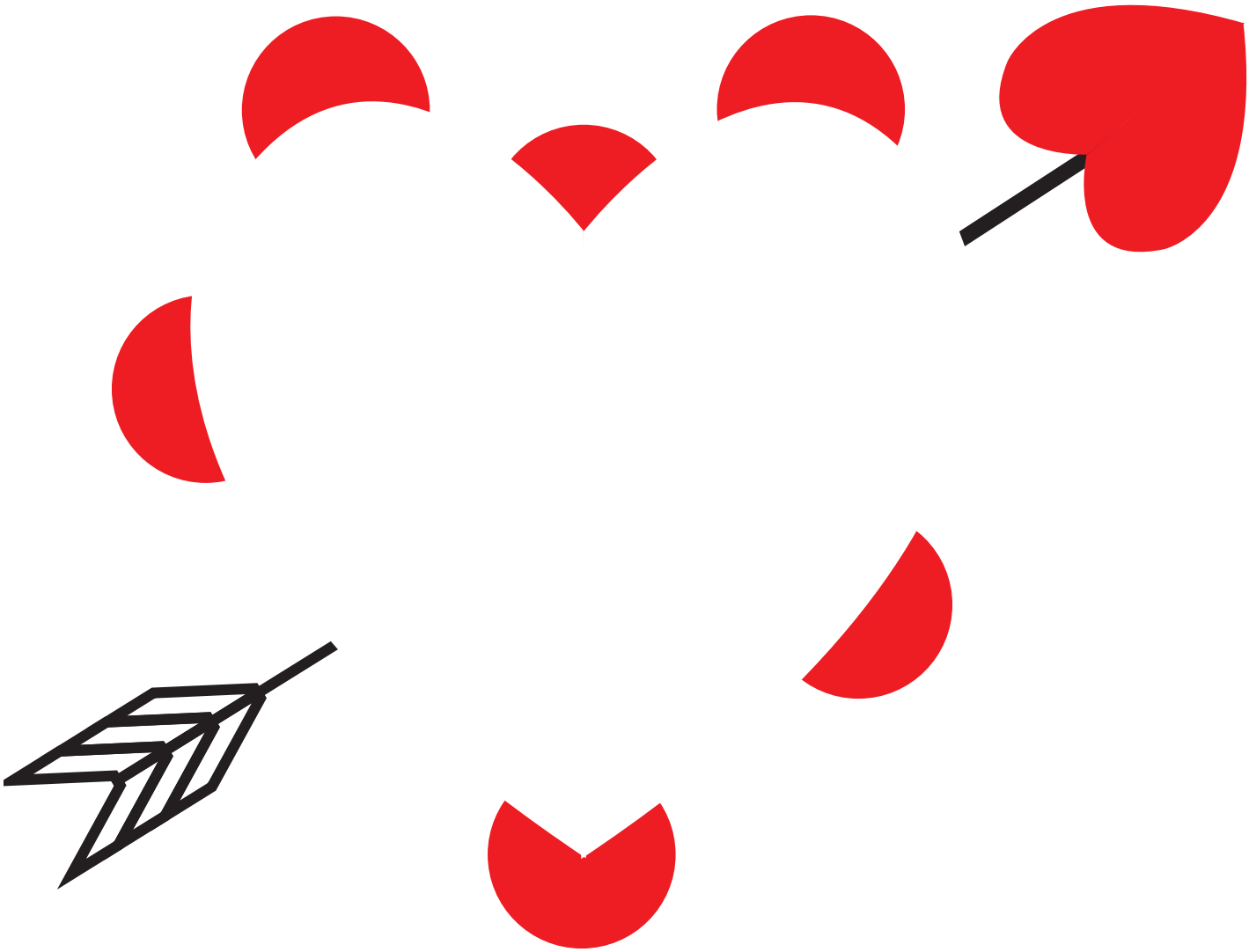
MELISSA THOMAS, ADAPTED FROM WWW.AMAZING-ILLUSION.COM (*top*); COURTESY OF G. SARCONE (*bottom*)

LOVE AND AMOR
Here we see that love and amor are two sides of the same ambiguous object. This sculpture is an ambigram—an artwork or typographical design that can be read from two different viewpoints. Judith Bagai, former editor of *The Enigma,* the official journal of the National Puzzlers' League, coined the term by contracting the words "ambiguous" and "anagram" (many ambigrams feature the same word seen from different directions).

AMBIGUOUS EMBRACES
Ambiguity is affected by our frame of mind. In the image at the bottom left, *Message of Love from the Dolphins,* adult observers see two nude lovers embracing, whereas young children see only dolphins. If you still can't see the dolphins (we promise you they are there), look for more than two. In the image at the bottom right, a Valentine's Day rose predicts the outcome of the evening's festivities.



COURTESY OF FRANCIS TABARY (*top*); SANDRO DEL PRETE *sandrodelprete.com* (*bottom*)



COURTESY OF SUSANA MARTINEZ-CONDE AND STEPHEN L. MACKNIK

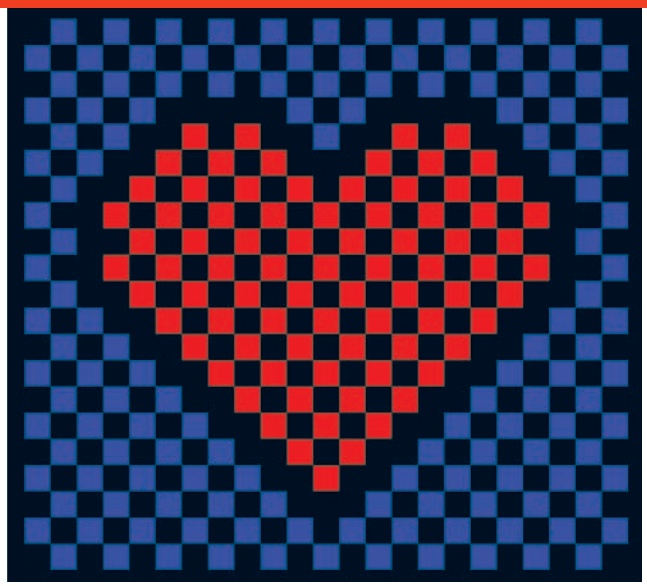
IS LOVE AN ILLUSION?

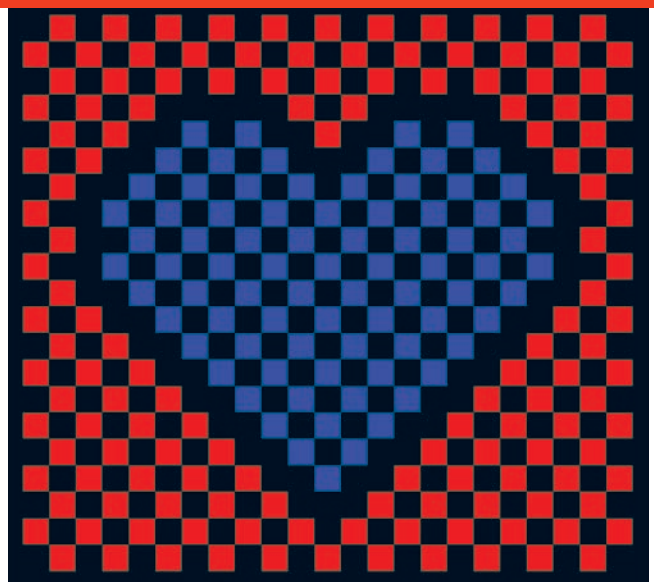
Spanish essayist Miguel de Unamuno said, "Love is the child of illusion and the parent of disillusion." Is this view cynical or biologically based? Illusions are, by definition, mismatches between physical reality and perception. Love, as with all emotions, has no external physical reality: it may be driven by neural events, but it is nonetheless a purely subjective experience. So, too, is the wounded heart we have drawn here. Where the arrow enters and exits the heart, there is no heart whatsoever, only an imaginary edge defined by the arrow.

This effect is called an illusory contour. We perceive the shape of the heart only because our brain imposes a shape on a very sparse field of data. Neuroscientist Rüdiger von der Heydt and his colleagues, then at University Hospital Zurich in Switzerland, showed that illusory contours are processed in neurons within an area of the brain called V2, which is devoted to vision. The illusory heart even looks slightly whiter than the background, although it is actually the same shade. Much of our day-to-day experience is made up of analogous feats of filling in the blanks, as we take what we know about the world and use it to imagine what we do not know.

FOR COFFEE AND TEA LOVERS
Yuan yang is a typical Hong Kong beverage mix of tea and coffee and also a symbol of marriage and love. Sculptor Tsang Cheung-shing has united both concepts in a beautiful ceramic work, in which tea and coffee poured from two stylish cups meet in a kiss.

COURTESY OF TSANG CHEUNG-SHING





POP! GOES MY HEART

Nothing is more romantic than curling up in front of a fire with your loved one on Valentine's Day as you lovingly whisper "chromostereopsis." Okay, maybe it's not as passionate as a sonnet—unless you are a vision scientist. Look at the red and blue hearts and examine their depth with respect to the background. Most people find that the red heart pops in front of the blue background, whereas the blue heart sinks beneath the red background.

This illusion comes about because the lenses in our eyes refract blue light more than red. This phenomenon is called chromatic aberration; another example of this effect is seeing a rainbow when you shine white light through a prism. When both eyes view the red and blue images simultaneously, the cornea and lens of the eyes refract different amounts of the colors. The brain deals with this sensory aberration by imagining depth even though all the elements in the images are in the same plane.

LOVE IS ALL AROUND

Romance is not just for humans and prairie voles. Elephants also embrace the concept.

COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University (top)*; SUKREE SUKPLANG *Corbis (bottom)*

ART AS VISUAL RESEARCH: Kinetic Illusions IN OP ART

By Susana Martinez-Conde and Stephen L. Macknik

Art and neuroscience combine to create fascinating examples of illusory motion

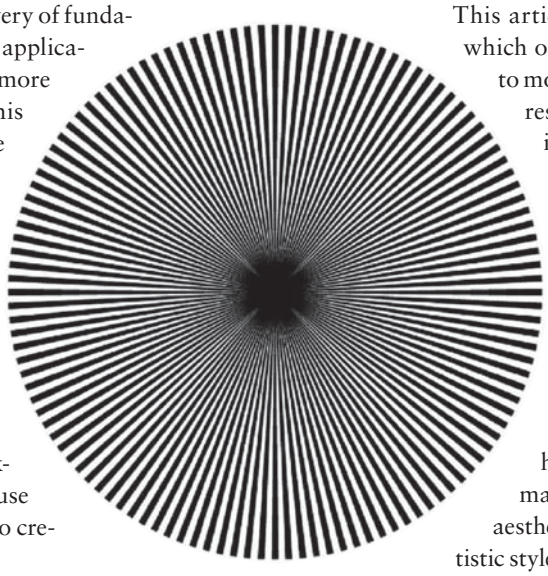
Scientists did not invent the vast majority of visual illusions. Rather they are the products of artists who have used their insights into the workings of the human eyes and brain to create illusions in their artwork. Long before visual science existed as a formal discipline, artists had devised techniques to "trick" the brain into thinking that a flat canvas was three-dimensional or that a series of brushstrokes in a still life was in fact a bowl of luscious fruit. Thus, the visual arts have sometimes preceded the visual sciences in the discovery of fundamental vision principles through the application of methodical—though perhaps more intuitive—research techniques. In this sense, art, illusions and visual science have always been implicitly linked.

It was only with the birth of the op art (for "optical art") movement that visual illusions became a recognized art form. The movement arose simultaneously in Europe and the U.S. in the 1960s, and in 1964 *Time* magazine coined the term "op art." Op art works are abstract, and many consist only of black-and-white lines and patterns. Others use the interaction of contrasting colors to create a sense of depth or movement.

This style became hugely popular after the Museum of Modern Art in New York City held an exhibition in 1965 called "The Responsive Eye." In it, op artists explored many aspects of visual perception, such as the relations among geometric shapes, variations on "impossible" figures that could not occur in reality, and illusions involving brightness, color and shape perception. But "kinetic," or motion, illusions drew particular interest. In these eye tricks, stationary patterns give rise to the powerful but subjective perception of (illusory) motion.

This article includes several works of art in which objects that are perfectly still appear to move. Moreover, they demonstrate that research in the visual arts can result in important findings about the visual system. Victor Vasarely, the Hungarian-French founder of the op art movement, once remarked, "In basic research, intellectual rigor and sentimental freedom necessarily alternate."

Op artists have created some of the illusions featured here; vision scientists honoring the op art tradition have created others. But all of them make it obvious that the link between aesthetics and illusory perception is an artistic style in and of itself.



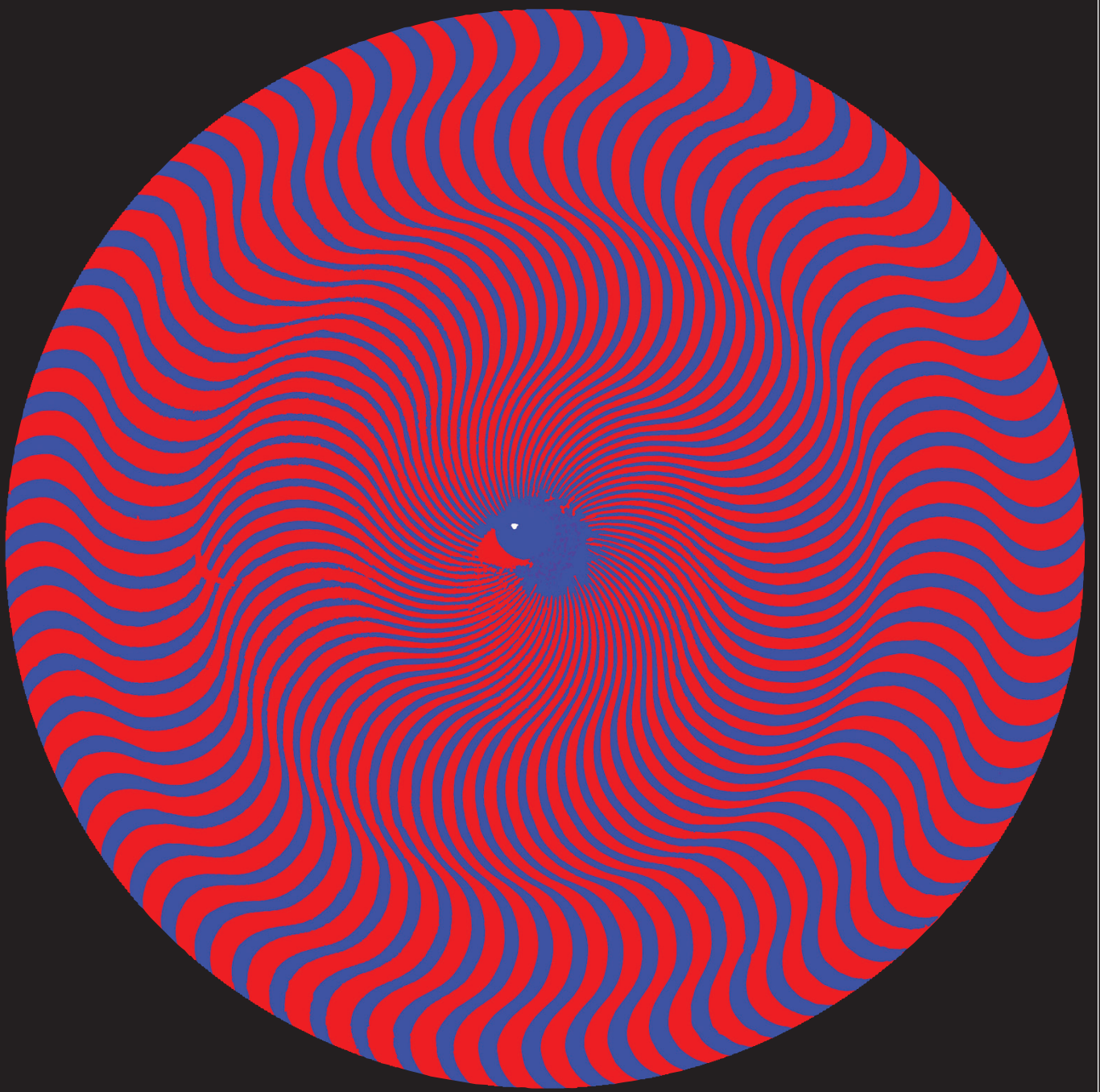
MacKAY RAYS

This illusion, created in 1957 by neuroscientist Donald M. MacKay, then at King's College London, shows that simple patterns of regular or repetitive stimuli, such as radial lines (called MacKay rays) can induce the perception of shimmering or illusory motion at right angles to those of the pattern. To see the illusion, look at the center of the circle and notice the peripheral shimmering.

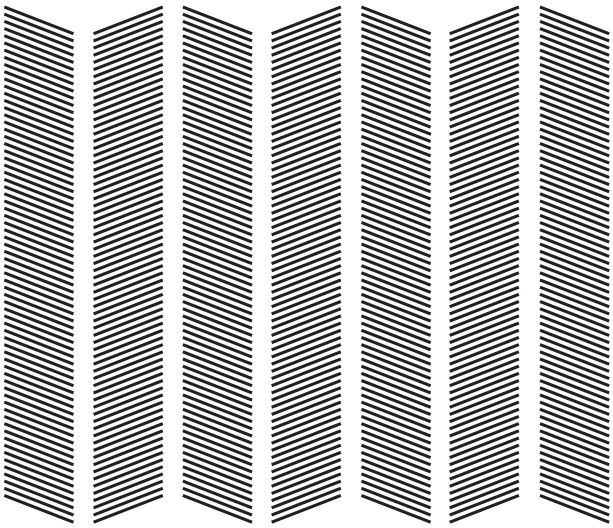
FROM "TRAVERSING THE HIGHWIRE FROM POP TO OPTICAL," BY CHRISTOPHER W. TYLER, IN *PLOS BIOLOGY*, VOL. 3, NO. 4; APRIL 2005

RILEY REVISITED

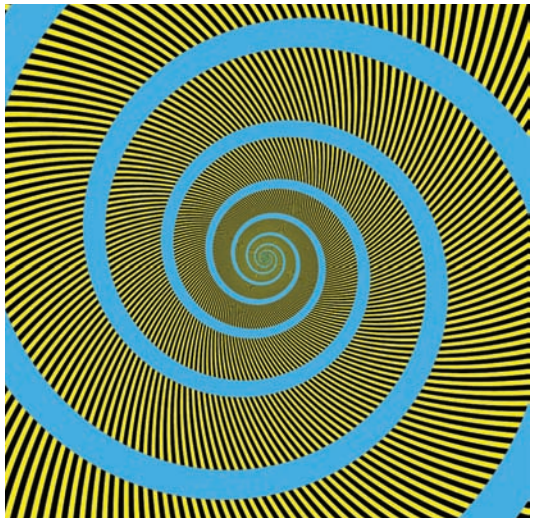
In a work reminiscent of British op artist Bridget Riley's, vision scientist Nick Wade of the University of Dundee in Scotland created an example that features both streaming and shimmering motion. An eye is clearly visible in the center of the design, and a face becomes visible if you view the illusion from across the room or shake your head. The hidden face is a portrait of Wade's wife, Christine, and the title *Chrystine* is a reference to the chrysanthemum shape.



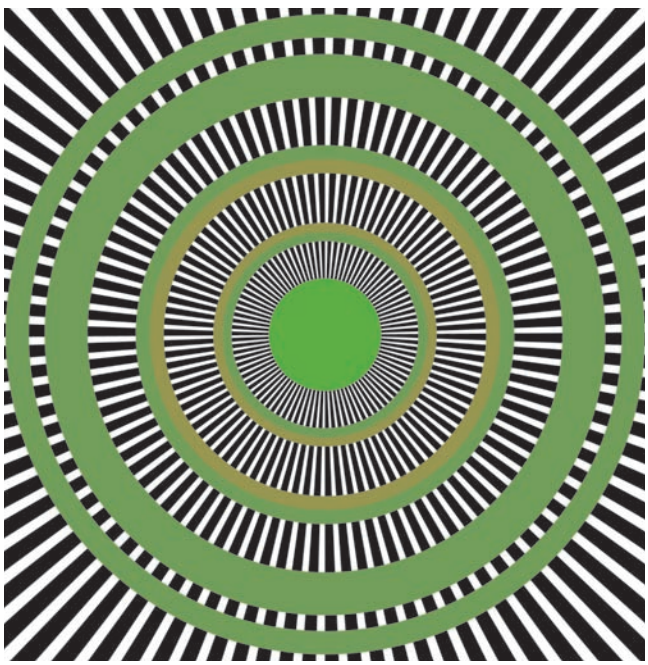
© NICHOLAS WADE

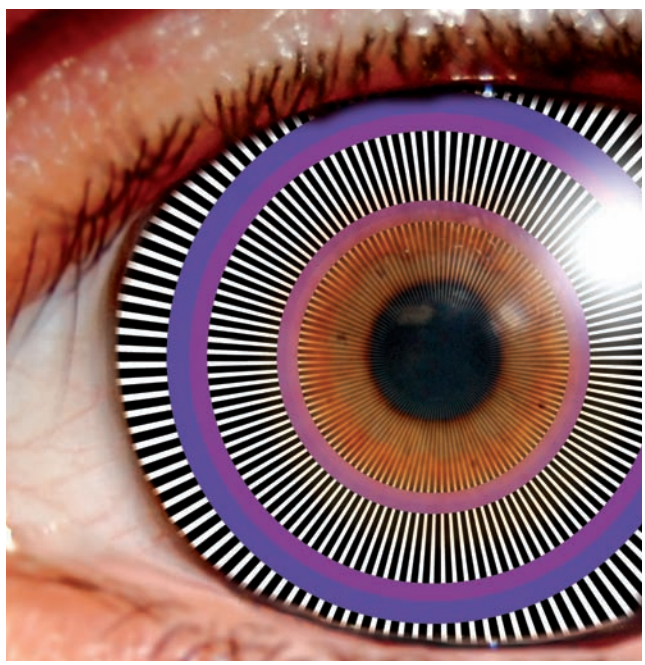


BBC WALLBOARD
This illusion began with a chance observation. MacKay first saw it on the wallboard of a BBC studio: the broadcasting staff had been annoyed by illusory shadows running up and down blank strips between columns of parallel lines.



OP ART IS ALIVE AND WELL
Akiyoshi Kitaoka, a professor of psychology at Ritsumeikan University in Japan, follows in the footsteps of the great op artists of the 20th century. *Waterway Spirals* is a compelling and powerful version of French op artist Isia Léviant's now classic *Enigma*. Observe the strong illusory motion along the blue spiraling stripe.



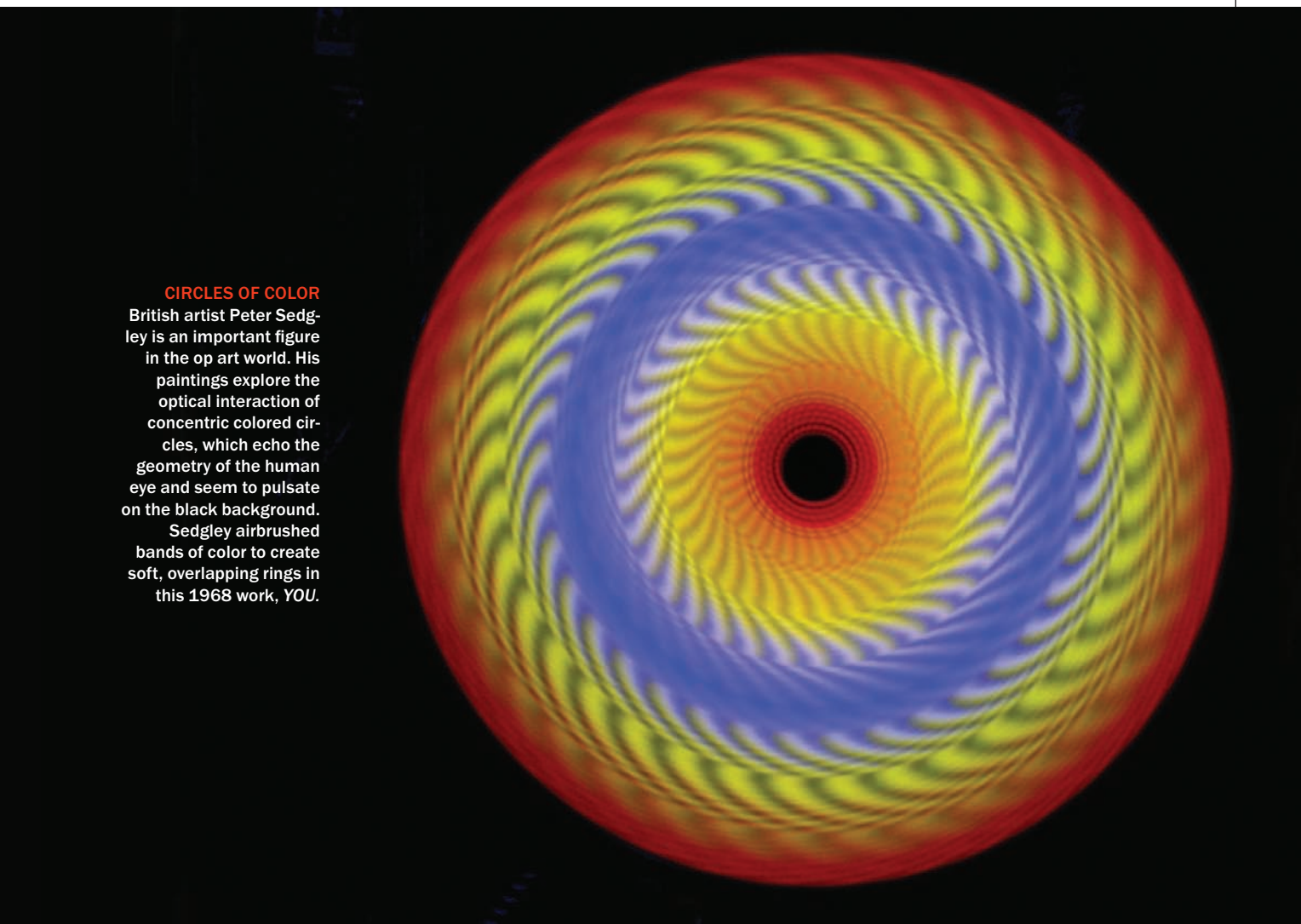


SCIENTIFIC AMERICAN MIND (*top left*); COURTESY OF AKIYOSHI KITAOKA *Ritsumeikan University* (*top right*); COURTESY OF JORGE OTERO-MILLAN *Barrow Neurological Institute/University of Vigo* (*bottom*)

***ENIGMA* ILLUSION**
Look at the center of the above image and notice how the concentric green rings appear to fill with rapid illusory motion, as if millions of tiny and barely visible cars were driving hell-bent for leather around a track. Neuroscientist and engineer Jorge Otero-Millan of the Barrow Neurological Institute in Phoenix created this image as a reinterpretation of *Enigma* by Léviant, who unknowingly combined the MacKay rays and the BBC wallboard illusions.

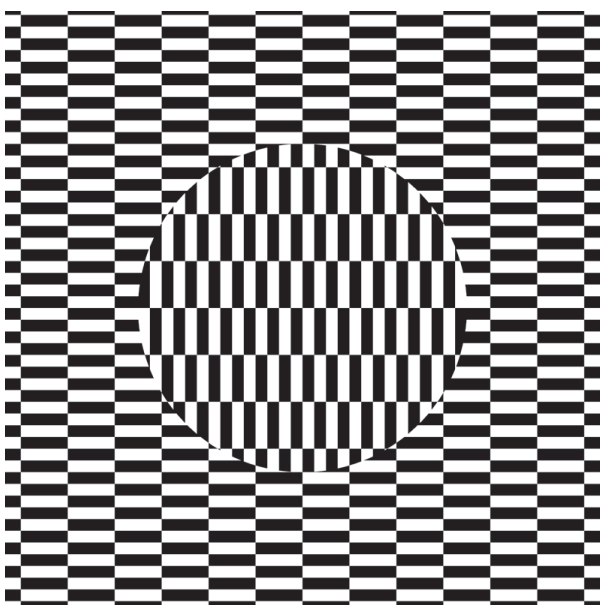
But does the *Enigma* illusion originate in the mind or in the eye? The evidence was conflicting until we found, in collaboration with our Barrow colleagues Xoana G. Troncoso and Otero-Millan, that the illusory motion is driven by microsaccades: small, involuntary eye movements that occur during visual fixation. The precise brain mechanisms leading to the perception of the illusion are still unknown, however. One possibility is that microsaccades produce small shifts in the geometric position of the peripheral areas of the image. These shifts produce repeated contrast reversals that could create the illusion of motion. Otero-Millan's *Enigmatic Eye* (*right*), also a tribute to *Enigma,* reflects the role of eye movements in the perception of the illusion.

Neuroscientist and artist Bevil Conway and his colleagues at Harvard Medical School have demonstrated that pairs of stimuli of different contrasts are able to generate motion signals in visual cortex neurons, and they have proposed that this neural mechanism may underlie the perception of illusory motion in certain static patterns.

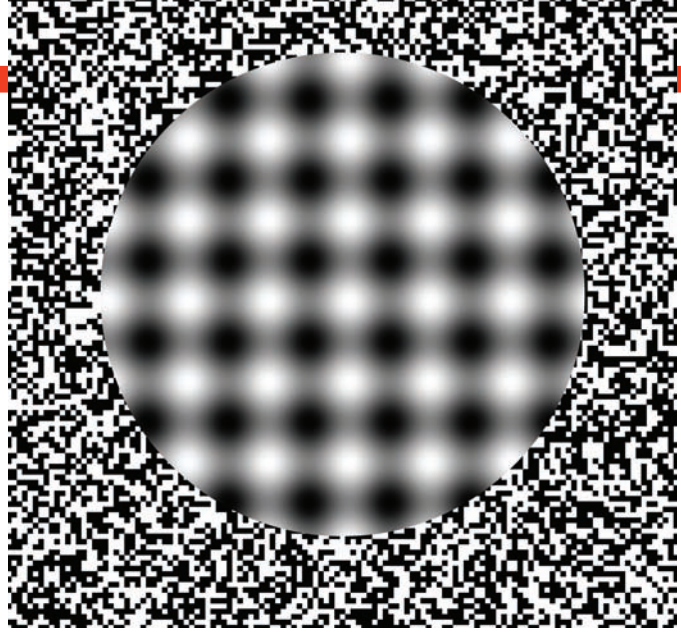


CIRCLES OF COLOR
British artist Peter Sedgley is an important figure in the op art world. His paintings explore the optical interaction of concentric colored circles, which echo the geometry of the human eye and seem to pulsate on the black background. Sedgley airbrushed bands of color to create soft, overlapping rings in this 1968 work, *YOU.*

OUCHI-SPILLMANN ILLUSION
Move your head back and forth as you let your eyes wander around the image and see how the circle and its background appear to shift independently of each other. Vision scientist Lothar Spillmann, then at the University of Freiburg in Germany, stumbled on the illusion while browsing Japanese op artist Hajime Ouchi's book *Japanese Optical and Geometrical Art,* which was first published in 1973. Spillmann then introduced the illusion to the vision sciences community, where it has enjoyed immense popularity.

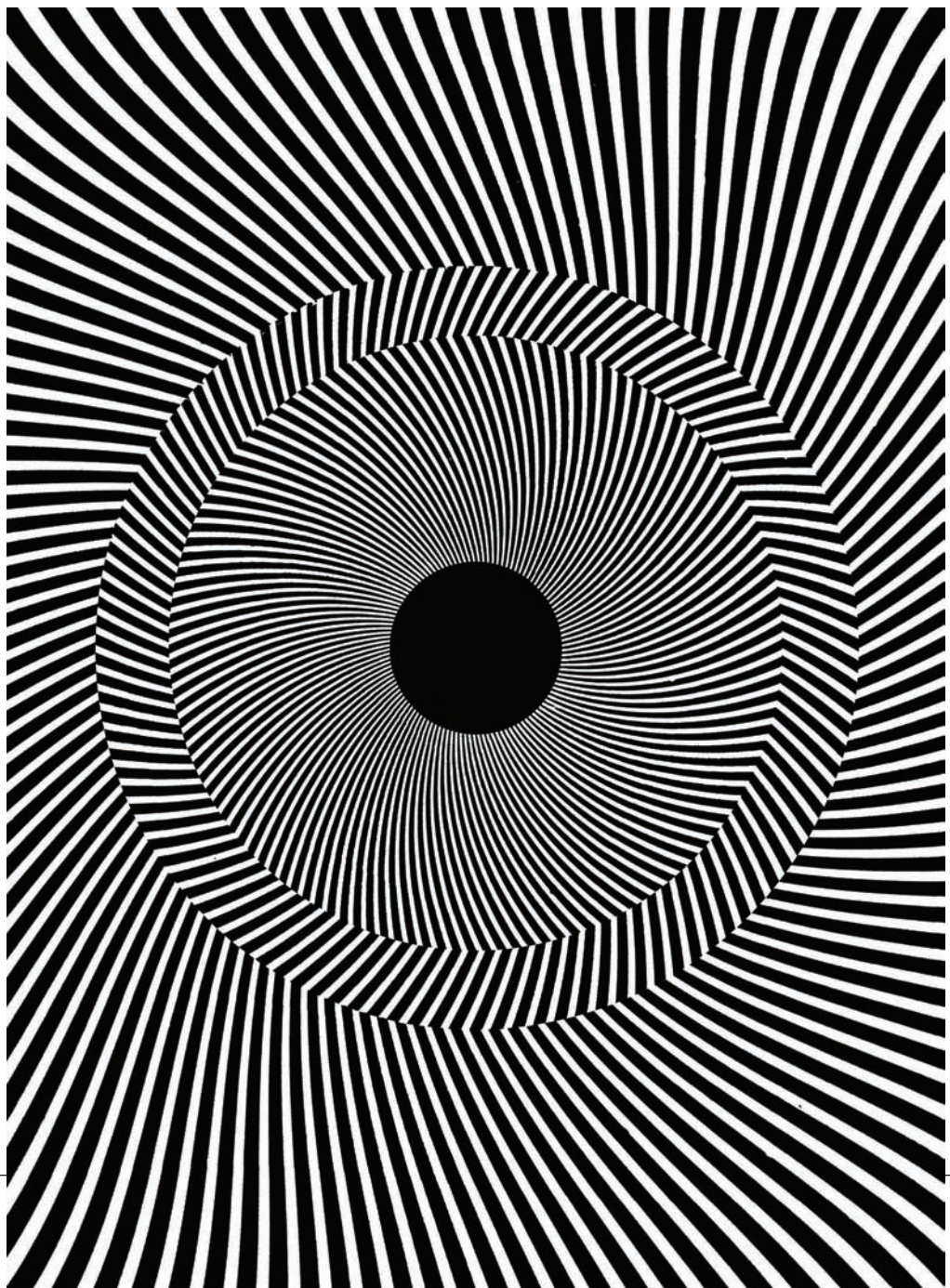


COURTESY OF PETER SEDGLEY (*top*); FROM *JAPANESE OPTICAL AND GEOMETRICAL ART,* BY HAJIME OUCHI. DOVER PUBLICATIONS, 1977 (*bottom*)

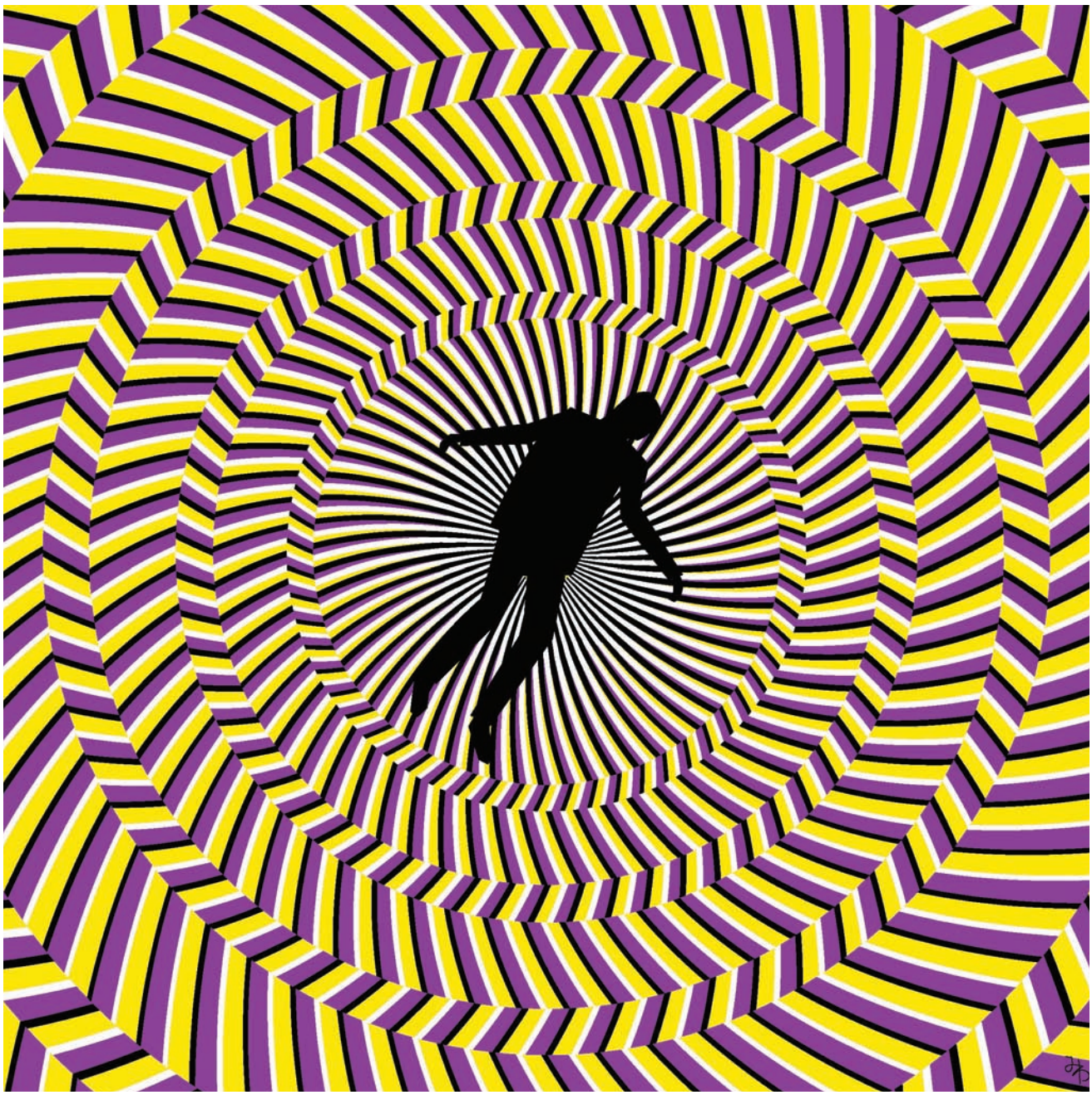


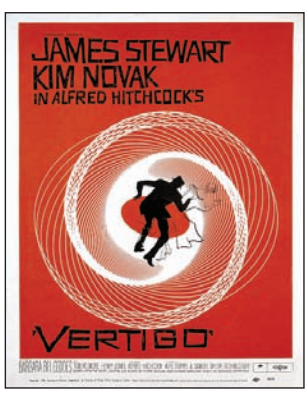
HOMAGE TO OUCHI
This illusion is a contemporary variation on the Ouchi pattern, drawn by Kitaoka in 2001.

ROTATING-TILTED-LINES ILLUSION
An illusion developed by vision scientists Simone Gori and Kai Hamburger, then at the University of Freiburg in Germany, is a novel variation of both the *Enigma* effect and Riley's *Blaze*. To best observe the illusion, move your head closer and then farther away from the page. As you approach the image, notice that the radial lines tilted to the right appear to rotate counterclockwise. As you move away from the image, they appear to rotate clockwise. This illusion was featured in the first edition of the Best Illusion of the Year Contest, held in 2005 in Spain (see http://illusionoftheyear.com/2005/rotating-tilted-line-illusion).



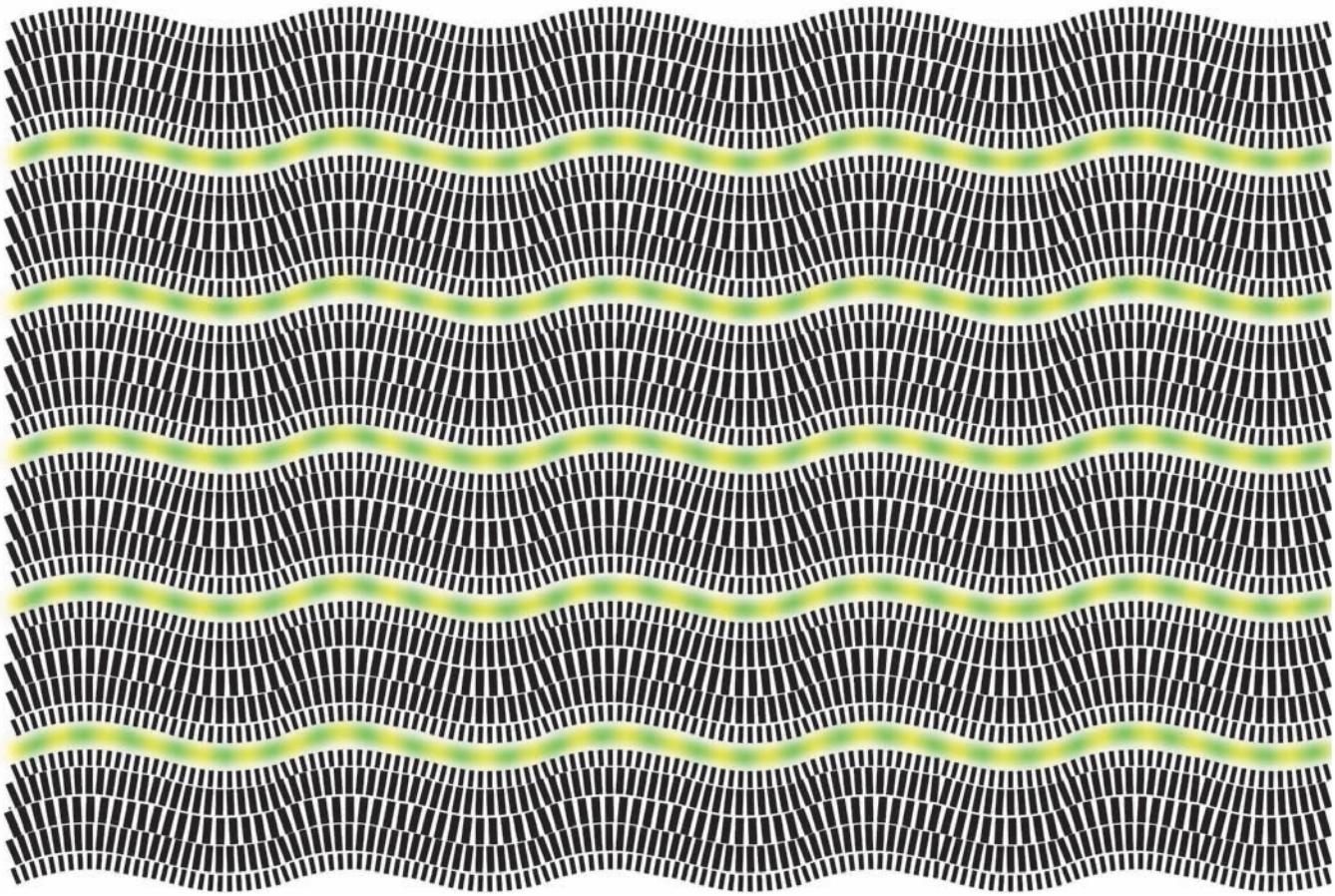
COURTESY OF AKIYOSHI KITAOKA *(top)*; FROM "A NEW MOTION ILLUSION: THE ROTATING-TILTED-LINES ILLUSION," BY SIMONE GORI AND KAI HAMBURGER, IN *PERCEPTION*, VOL. 35, NO. 6; 2006. REPRINTED WITH PERMISSION FROM PION LTD, LONDON *(bottom)*



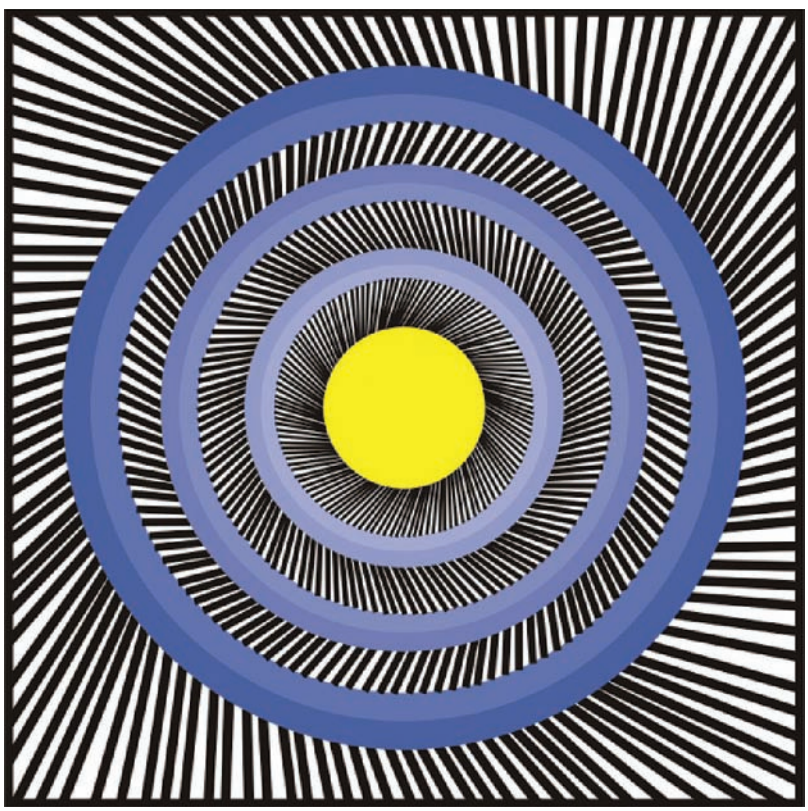


VERTIGO
Artist Miwa Miwa's variant of the rotating-tilted-lines illusion (*above*) pays homage to *Vertigo*, the classic 1958 film by Alfred Hitchcock (*left*).

COURTESY OF MIWA MIWA (*top*); PARAMOUNT/THE KOBAL COLLECTION AT ART RESOURCE, NY (*bottom*)

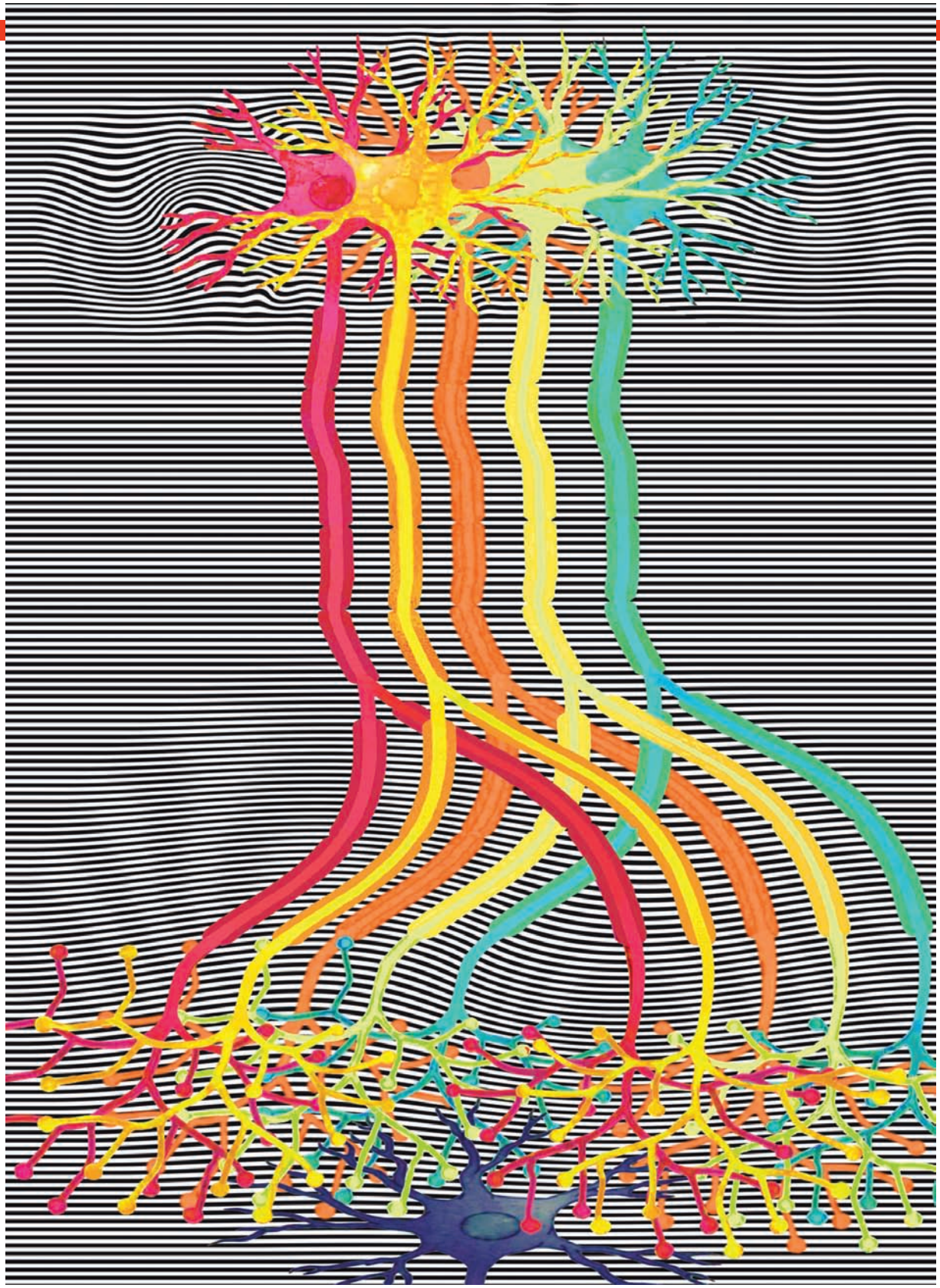


CHRISTMAS LIGHTS ILLUSION
The Christmas lights illusion, by Italian artist and author Gianni A. Sarcone, is also based on Léviant's *Enigma*. Notice the appearance of a flowing motion along the green-yellow stripes.



TWO IN ONE
Gori and Hamburger's combination of the rotating-tilted-lines illusion and the *Enigma* illusion is both visually arresting and a powerful demonstration of illusory motion from a static pattern. The *Enigma* illusion, some three decades after its creation by Léviant, continues to inspire visual science as well as visual arts.

COURTESY OF G. SARCONE, © 2002 *(top)*; FROM "A NEW MOTION ILLUSION: THE ROTATING-TILTED-LINES ILLUSION," BY SIMONE GORI AND KAI HAMBURGER, IN *PERCEPTION*, VOL. 35, NO. 6; 2006. REPRINTED WITH PERMISSION FROM PION LTD, LONDON *(bottom)*



COURTESY OF JOSÉ FERREIRA W./KINOGENIA.COM

ART MEETS SCIENCE

This work by French artist José Ferreira W., *Nerve Impulse,* not only reprises the *Enigma* effect but also illustrates how nerve cells relay information from the eye to the brain: triggered by a flood of chemicals called neurotransmitters, nerve cells (*at top*) send electrical signals racing down slender structures called axons. At the axon's knoblike terminals, each nerve cell releases its own neurotransmitters, which diffuse across a narrow synapse gap and bind with receptors on the branchlike dendrites of the next nerve cell to trigger a new electrical signal. Each successive neuron conveys the message to its neighbor, like a bucket brigade passing a pail of water.

SCULPTING THE IMPOSSIBLE: Solid Renditions OF VISUAL ILLUSIONS

By Stephen L. Macknik and Susana Martinez-Conde

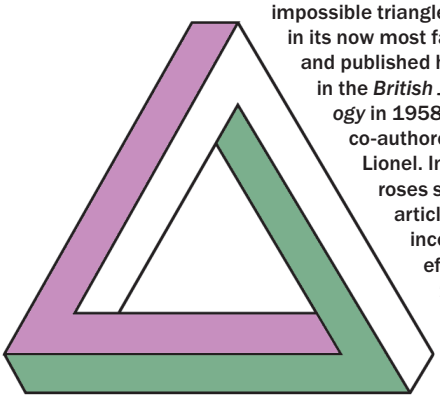
Artists find mind-bending ways to bring impossible figures into three-dimensional reality

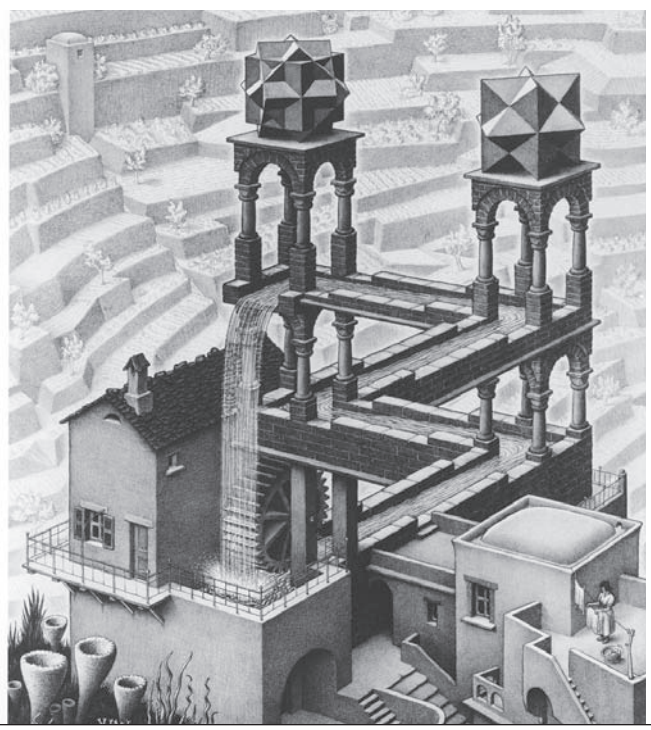
In an impossible figure, seemingly real objects—or parts of objects—form geometric relations that physically cannot happen. Dutch artist M. C. Escher, for instance, depicted reversible staircases and perpetually flowing streams. Mathematical physicist Roger Penrose drew his famously impossible triangle, and visual scientist Dejan Todorović of the University of Belgrade in Serbia created a golden arch that won him third prize in the 2005 Best Illusion of the Year Contest. These effects challenge our hard-earned perception that the world around us follows certain, inviolable rules. They also reveal that our brains construct the feeling of a *global* percept—an overall picture of a particular item—by sewing together multiple *local* percepts. As long as the local relation between surfaces and objects follows the rules of nature, our brain doesn't seem to mind that the global percept is impossible.

Several contemporary sculptors have taken up the challenge of creating impossible art. That is, they are interested in shaping real-world 3-D objects that nonetheless appear to be impossible. Unlike classic monuments—such as the Lincoln Memorial in Washington, D.C.—which can be perceived by either sight or touch, impossible sculptures can be interpreted (or *misinterpreted*, as the case may be) only by the visual mind.

PENROSE TRIANGLE

The impossible triangle (also called the Penrose triangle or the tribar) was first created in 1934 by Oscar Reutersvärd. Roger Penrose attended a lecture by M. C. Escher in 1954 and was inspired to rediscover the impossible triangle. Penrose (who at the time was unfamiliar with the work of Reutersvärd, Piranesi and other previous discoverers of the impossible triangle) drew the illusion in its now most familiar form (*left*) and published his observations in the *British Journal of Psychology* in 1958, in an article co-authored with his father, Lionel. In 1961 the Penroses sent a copy of the article to Escher, who incorporated the effect into *Waterfall,* one of his most famous lithographs (*right*).

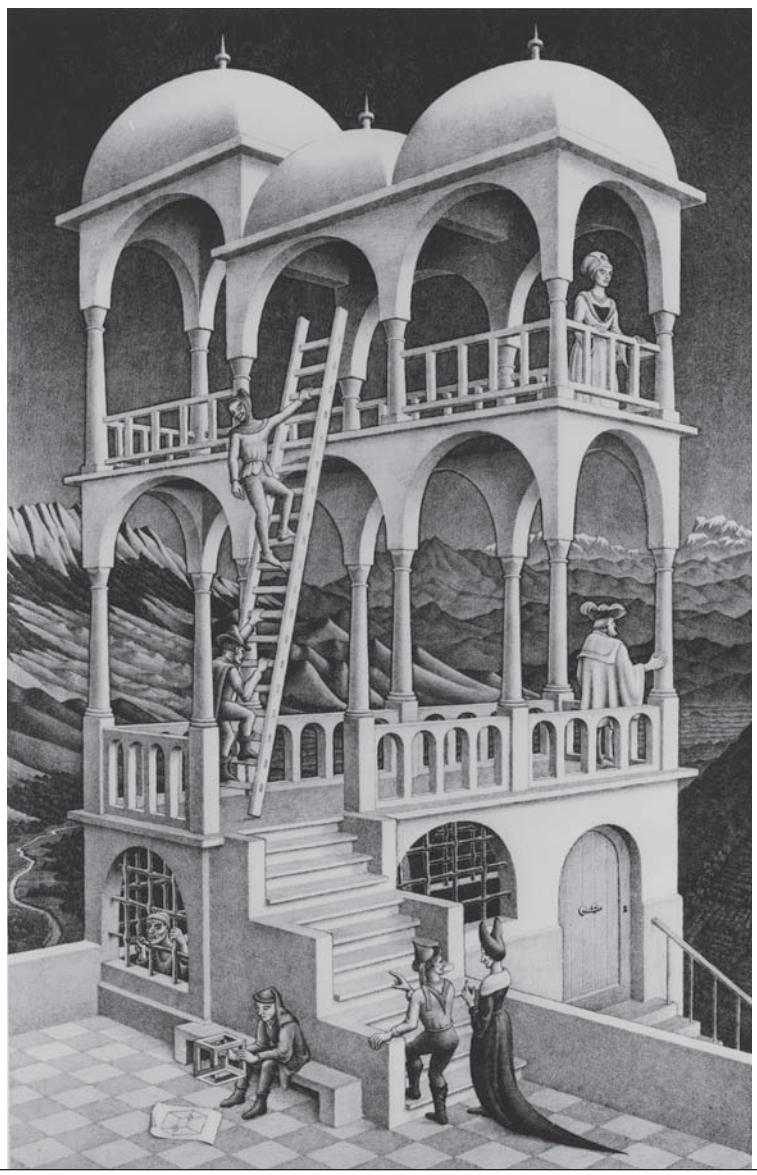




SCIENTIFIC AMERICAN MIND (*left*); M. C. ESCHER'S *WATERFALL*, © 2013 THE M. C. ESCHER COMPANY-THE NETHERLANDS. ALL RIGHTS RESERVED. WWW.MCESCHER.COM (*right*)

IMPOSSIBLE ARCH

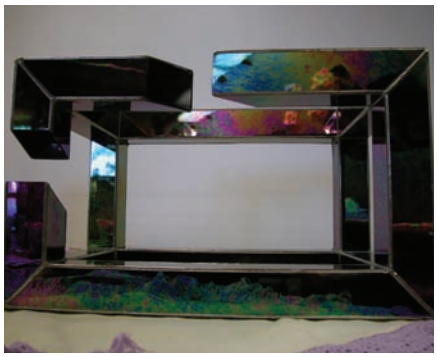
Elusive Arch, by Dejan Todorović, shows a new impossible figure. The left-hand part of the figure appears as three shiny oval tubes. The right-hand part looks corrugated, with three alternating pairs of shallow matte ridges and grooves. The bright streaks on the figure's surface are seen either as highlights at the peaks and troughs of the tubes or as inflections between grooves. Determining the direction of the apparent illumination falling on the figure is difficult: it depends on whether we interpret the light as falling on a receding or an expanding surface. Further, determining the exact position and shape of the transition region near the center of the arch is maddening because the local 3-D interpretations defy the laws of illumination. For more about the arch, see http://illusionoftheyear.com/2005/elusive-arch



HOMAGE TO ESCHER

Escher's *Belvedere* (*left*) showcases columns that switch walls between their bases and capitals, a straight ladder whose base rests inside the building yet nonetheless enters the building from the outside at its top, and a sitting man holding an impossible cube. Mathieu Hamaekers, a Belgian mathematician and sculptor, created an homage to *Belvedere* that features a real-life impossible cube. This photograph (*below*) shows the artist holding the sculpture *Upside Down,* built in 1985.

COURTESY OF DEJAN TODOROVIĆ *University of Belgrade (top)*; M. C. ESCHER'S *BELVEDERE*, © 2013 THE M. C. ESCHER COMPANY-THE NETHERLANDS. ALL RIGHTS RESERVED. WWW.MCESCHER.COM (*bottom left*); COURTESY OF MATHIEU HAMAEKERS (*bottom right*)



IMPOSSIBLE BOX
Hans Schepker has built outstanding sculptures of impossible objects, such as this *Crazy Crate* made from glass (*left*). Other views of the crazy crate show the method behind the madness (*center* and *right*). Notice that the illusion works only from a specific vantage point. At any other angle, the illusion fails. Scientists refer to this as the accidental view, but there is nothing accidental about it. To perceive the illusion, the view must be carefully staged and choreographed, or else the audience will fail to see the "impossible" sculpture.

BACKYARD MAGIC
The late magician Jerry Andrus created this crazy crate, shown here from two different angles, in his backyard. The photograph on the right reveals the magic.

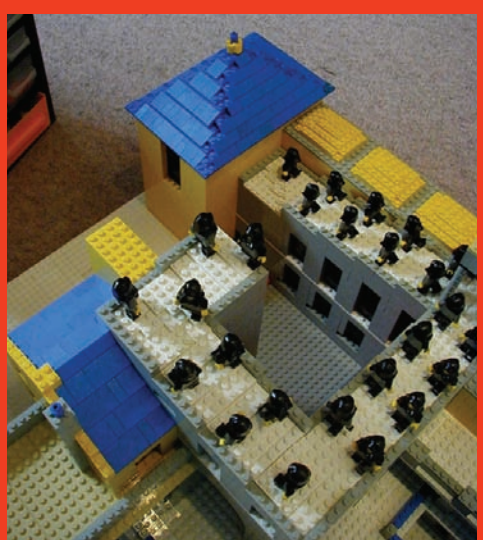
INDUSTRIAL-SIZE TRIANGLE
Artist Brian McKay created a giant version of the impossible triangle (*below, left*) in Perth, Australia, in collaboration with architect Ahmad Abas. How did they do that? A photograph taken from another angle (*below, right*) reveals the trick.

COURTESY OF HANS SCHEPKER (*top*); COURTESY OF GEORGE ANDRUS (*middle*); COURTESY OF BJØRN CHRISTIAN TØRRISSEN *bjornfree.com* (*bottom*)

A TWIST ON THE TRIANGLE
Unity, an impossible triangle created by Hamaekers in 1995, is now installed in Ophoven, Belgium. Again, the viewer's location relative to the object is critical. But in this case, Hamaekers used a different physical method to achieve the illusion.

A CLOSED TRIANGLE
Unlike most 3-D Penrose triangles, the sculptures by French artist and magician Francis Tabary are neither twisted nor open. They look impossible from a relatively large range of vantage points, although they do fail when seen from some viewpoints. The Tabary sculpture shown here is a four-cube-sided Penrose triangle.

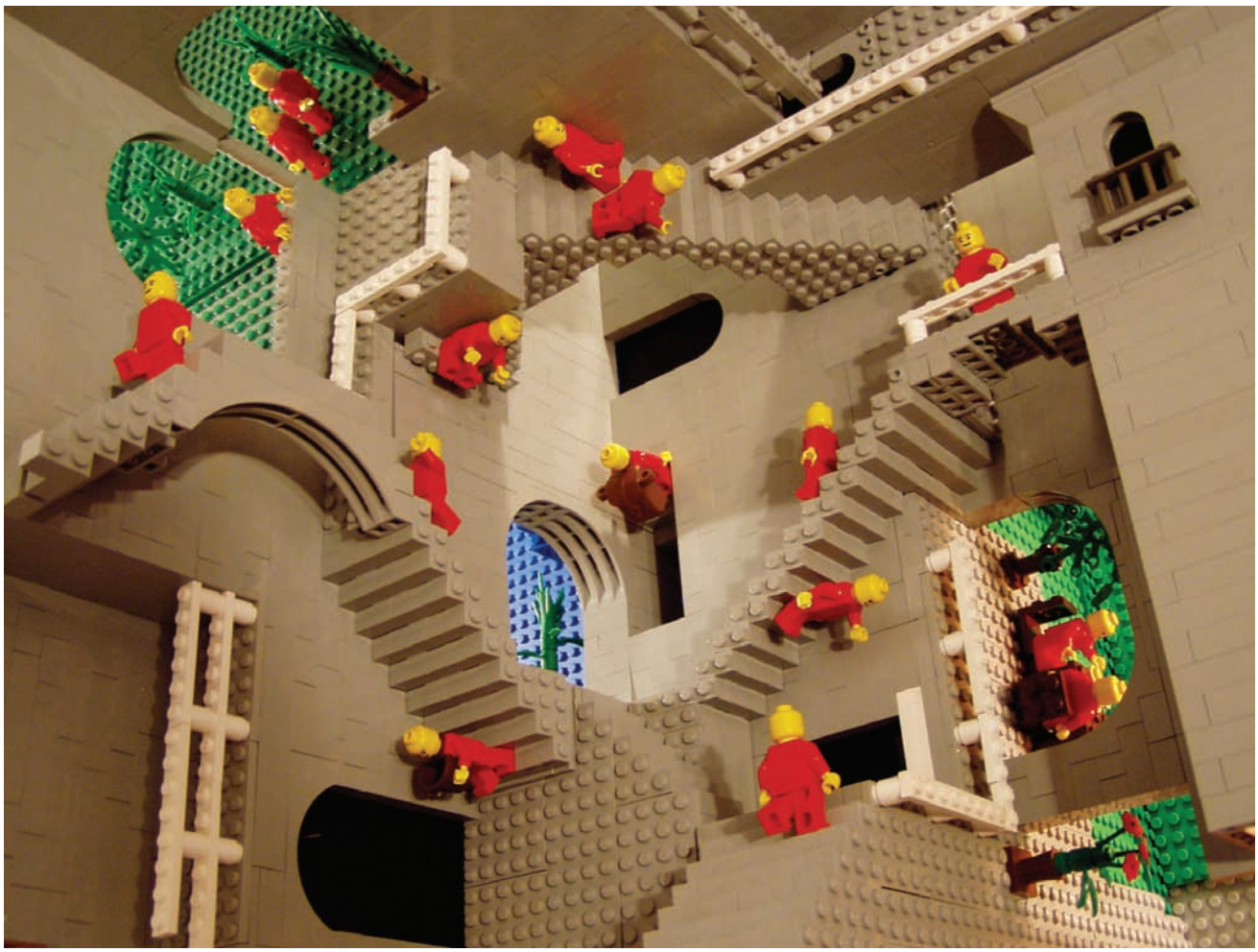
COURTESY OF MATHIEU HAMAEKERS (*top*); COURTESY OF FRANCIS TABARY (*bottom*)

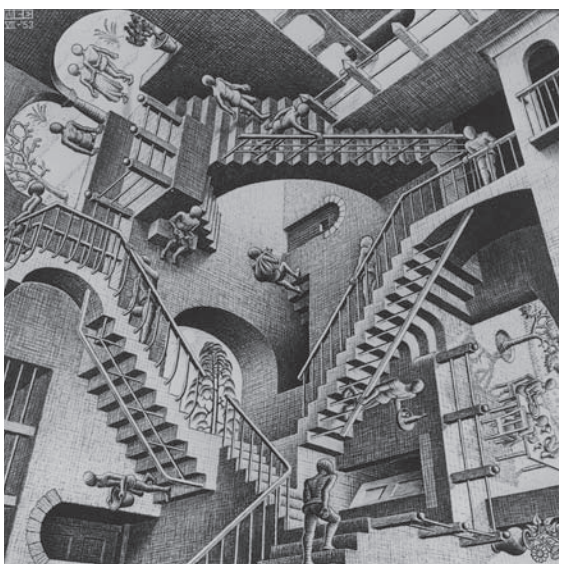


MAKING ESCHER 3-D
Andrew Lipson, a self-described "professional nerd" with no official connection to the Lego Group, and his friend Daniel Shiu have rendered five M. C. Escher works in Lego blocks, including this model of Escher's *Ascending and Descending* (*top*). The original work by Escher, a 1960 lithograph, shows a large building with an endless staircase on its roof (*bottom right*). Some of the people are ascending the staircase, while others are descending.

Lipson and Shiu spent considerable time studying Escher's work before beginning construction. In their photograph of the finished sculpture, it looks as if the staircase is continuous. But in this picture taken from another angle (*bottom left*), you can see that the edges of the staircase do not meet. The Lego illusion works only if the photograph is taken from exactly the right viewing angle.

CONSTRUCTION BY ANDREW LIPSON AND DANIEL SHIU; PICTURES COURTESY OF A. LIPSON (*top* and *bottom left*); M. C. ESCHER'S *ASCENDING AND DESCENDING*, © 2013 THE M. C. ESCHER COMPANY-THE NETHERLANDS. ALL RIGHTS RESERVED. WWW.MCESCHER.COM (*bottom right*)





CONSTRUCTION BY ANDREW LIPSON AND DANIEL SHIU; PICTURES COURTESY OF A. LIPSON (*top* and *bottom right*); M. C. ESCHER'S *RELATIVITY*, © 2013 THE M. C. ESCHER COMPANY-THE NETHERLANDS. ALL RIGHTS RESERVED. WWW.MCESCHER.COM (*bottom left*)

IT'S ALL RELATIVE

Lipson and Shiu also worked together on a Lego rendition of Escher's *Relativity* (*top*). The original version, a popular lithograph first printed by Escher in 1953, depicts a surreal architectural structure in which there seem to be three separate sources of gravity (*bottom left*). The stairways are double-sided, and each stair is double-treaded.

A photograph taken from a slightly different angle and farther away (*bottom right*) shows how the sculpture is made. Lipson and Shiu used lots of scaffolding to hold it up. This was their fourth Escher picture rendered in Lego blocks.

ONE-MAN BAND

Encore, by the late Japanese artist Shigeo Fukuda, uses similar principles to represent a pianist and violinist in the same sculpture when viewed from two vantage points. You can see only half of the duet at once, and neither is visible unless the sculpture is viewed from the side.

MIRROR IMAGE

Another work by Fukuda, *Underground Piano,* looks like a pile of piano parts unless you stand in the right place and view the "reassembled" piano in the mirror.

SHADOW PLAY

Fukuda welded together 848 forks, knives and spoons to make *Lunch with a Helmet On.* Here he cleverly resolves the illusion by placing a light at the critical vantage point, making the motorcycle obvious only in the shadow cast by the utensil pile.

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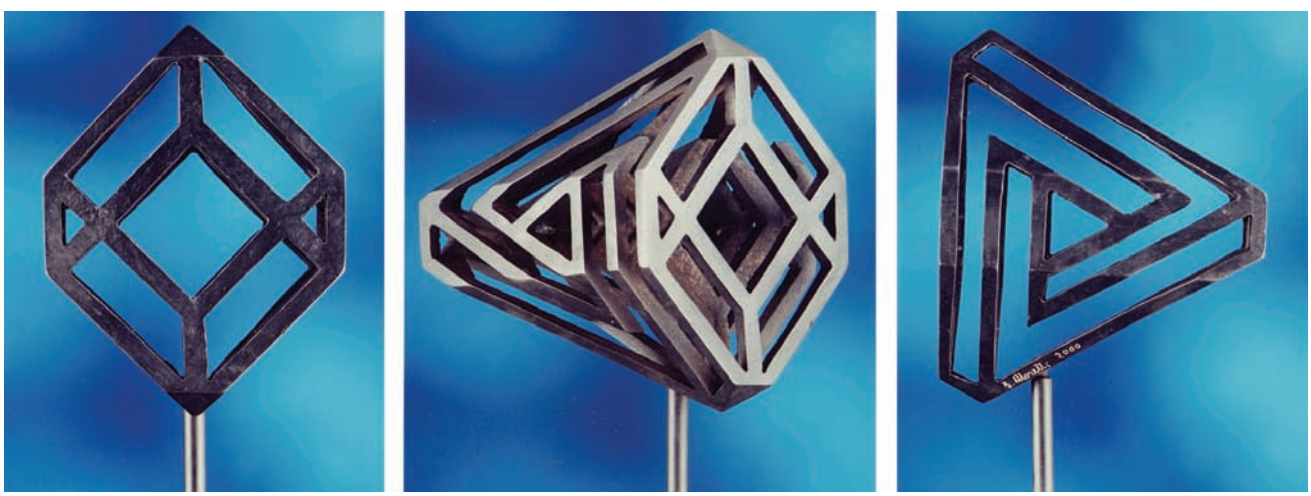
IMELDA'S DREAM COME TRUE

Imelda Marcos, widow of the former Philippines dictator Ferdinand Marcos, was infamous for her shoe collection but also for quotes such as this one: "People say I'm extravagant because I want to be surrounded by beauty. But tell me, who wants to be surrounded by garbage?" Well, Imelda, now you can be surrounded by both, courtesy of artists Tim Noble and Sue Webster, who create eye-catching artwork from rubbish. In 1998 Noble and Webster created this sculpture, *Dirty White Trash (with Gulls),* using six months' worth of their own garbage. Like Fukuda, they used a strategically placed light source to cast their own shadows on the wall. The sculpture appeared in a 2003 exhibition at the P.S.1 Contemporary Art Center in Long Island City, N.Y.

AND THE WINNER IS ...

For several years, Italian sculptor Guido Moretti has donated copies of his *Three-Bar Cube* and other impossible sculptures as trophies for the Best Illusion of the Year Contest. Depending on your vantage point, *Three-Bar Cube* can appear to be a cube, a solid structure or an impossible triangle.

For more information, see http://illusionoftheyear.com/trophies



COURTESY OF P.S.1 CONTEMPORARY ART CENTER *(top)*; COURTESY OF GUIDO MORETTI *www.guidomoretti.it (bottom)*

Truer THAN TRUTH

By Susana Martinez-Conde and Stephen L. Macknik

Trompe l'oeil illusions challenge your perception

I always tell the truth. Even when I lie.
—Al Pacino in
Scarface, 1983

IN THE STUDIO of sculptor Tom Eckert, life appears to imitate art. A new snow shovel—Eckert cannot get much use of it in Tempe, Ariz.—hangs on the back wall, covered by a sheer piece of fabric. We had seen photographs of Eckert's art before our visit, so we suspect that the translucent curtain is carved out of wood. But the trick is on us. Eckert reveals that the shovel is wood as well, as is the "plastic" hook holding it and the two not really galvanized metal nails securing the curtain to the wall. Instead a metal fastener hidden in the back supports the entire piece, and the shovel's filmy silhouette is spray-painted onto the solid wood block that is the faux silk curtain. Elsewhere in the studio, we mistake wood sculptures for balled-up used work rags, and vice versa. Is the rag abandoned on the workbench a model for a sculpture, or are we looking at the carving instead? Only after touching it can we decide.

COURTESY OF LEANDRO ERLICH STUDIO

SWIMMING POOL
Argentine artist Leandro Erlich is the author of this permanent art installation at the 21st Century Museum of Contemporary Art, Kanazawa, in Japan. Observers from above enjoy the sight of undisturbed underwater breathers, while visitors meandering "inside" the pool experience blurry vision when they look up at the "surface" (a thin layer of glass covered by water).

MURAL BY DEREK BESANT;
PHOTOGRAPH COURTESY OF TOMAS ROSENFELD

BEHIND THE CURTAIN

The Flatiron Mural is artist Derek Besant's milestone outdoor public trompe l'oeil mural for the city of Toronto in Canada. The back end of the Gooderham Flatiron Building, a magnificent 1893 Victorian triangular structure with turrets and coned rooflines at the heart of Toronto's Theatre District and St. Lawrence Market, was knocked down to create a park, and five windows were punched into the firewall facade, creating an aesthetic problem. "My solution was to apply aspects of the surrounding five blocks of architecture into a sculptural facade that appears to be a giant curtain," Besant says.

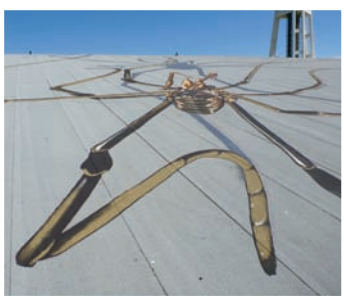
TRUE LIES

According to legend, trompe l'oeil ("to trick the eye" in French) originated in a competition between artists Zeuxis and Parrhasius in ancient Greece. Zeuxis painted such lavishly appetizing grapes that birds tried to eat them. Sure of his victory, he attempted to unveil Parrhasius' painting but was crushed to realize that the curtain he tried to pull aside was the art itself. Trompe l'oeil illusions work because your visual system uses position, shading and even the interplay of light on an object's surface to build a mental representation of the world around you. Tom Eckert, a modern-day Parrhasius, does not consider himself a trompe l'oeil artist, however. "Trompe l'oeil implies mimicry," Eckert says. "I create illusions." Indeed, pieces such as *The Raising of the Sphere* appear to defy the laws of nature rather than emulate them. The "silk" cloth raising the ivory ball is not fabric but wood. The thinness, detail and luster of the carving deceive our visual neurons, and we conclude that the material must lack the structural integrity to support a large, heavy object, despite what we see. The end result is not the perception of a masterful wood carving but of magic and the impossible.

ATTACK OF THE GIANT ARACHNIDS

One way to achieve spectacular trompe l'oeil illusions is through the use of anamorphic perspective. Artist Marlin Peterson painted harvestmen (which, although they are arachnids, are not actual spiders) on a Seattle rooftop. The images are stretched so as to optimize 3-D perception for viewers at the observation level of the Space Needle; other vantage points diminish the illusion. As in many trompe l'oeil illusions accomplished by painting, the expert use of shadows is critical. Peterson needed six gallons of house paint and a full-body harness to create this artwork.

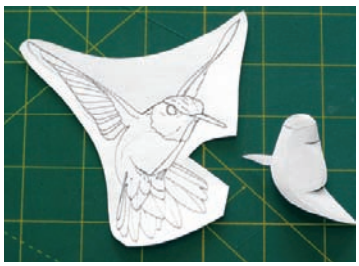
You can see the major steps of the process in a short video at http://marlinpeterson.com/2-minute-video-of-the-whole-mural



CLONES AND MIRAGES

As a young child in the backseat of the family car on a long hot Arizona highway, Eckert was struck by the persistent sight of water on the road. His parents told him it was a mirage, an illusion. He was stunned. The epiphany marked the beginning of a lifelong fascination with the boundaries of reality and our perception of it. Today Eckert is a producer of mirages. The shovel propped up against the wall is the real-world prototype of a hanging carved wood sculpture. Road mirages work because blue photons from the sky refract from the surface between cool and hot air just above the asphalt. Similarly, Eckert uses paint and carving techniques in such a way that light helps to evoke materials other than wood. Your brain sees luster and interprets it as the sheen of metal, for instance. Eckert's shovel also exemplifies the perceptual principle known as amodal completion, by which we infer a whole object even if some of its parts are occluded. Eckert did not need to carve a shovel handle, or even a full blade, to create the illusion of the complete tool. Just a touch of spray paint over the fabric "veiling" the implement, and our amodal completion mechanisms take care of the rest.

COURTESY OF TOM ECKERT (*top and bottom*); MARLIN PETERSON (*middle*)



OUTSIDE THE BOX

Consummate trompe l'oeil artists make their creations jump out of the frame, sometimes literally, as in Spanish Catalan painter Pere Borrell del Caso's *Escaping Criticism* (*right*). Paper sculptor Calvin Nicholls pulls off the illusion by creating actual 3-D objects from small pieces of paper (*above left*). He starts with a 2-D detail drawing, which becomes a pattern for all the paper pieces he will cut (*above right*). Then he traces individual pieces from the drawing and transfers them to the actual paper used in the sculpture, attaching them with minute amounts of glue.

HANDCRAFT

Painter Annie Ralli and photographer Ray Massey give new meaning to the term "handwriting." If you have not seen the illusion yet, look again: *There. Is. No. Pen.* The illusion is part of a series for Ecclesiastical Insurance, a company using the tagline "You're in good hands." Notice how cleverly the pen's "metal" clip disguises the index finger's first knuckle. The perceptual principle known as good continuation (our perception that the paint lines defining the pen make up a single uninterrupted object) plays a big role in the deception.

COURTESY OF CALVIN NICHOLLS/CALVINNICHOLLS.COM (*top*); COURTESY OF PERE BORRELL DEL CASO (*middle*); RAY MASSEY (*bottom*)

(Further Reading)

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PERFECTLY TIMED Advertising

By Stephen L. Macknik, Leandro Luigi Di Stasi and Susana Martinez-Conde

Marketing illusions that make time fly

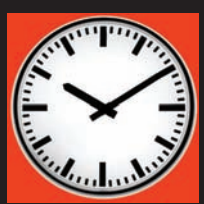
Time is the most valuable thing a man can spend.
—Theophrastus (371–287 B.C.)

ANCIENT philosophers were far from alone in their musings about time. Playwright Tennessee Williams wrote in 1944 that time is the longest distance between two places. And the years since have proved him right. Fast travel, instant communications and express deliveries between opposite ends of the world mean, more than ever, that time is not only relative but also an illusion.

But time is also money—or so the axiom goes. Certainly both time and money are precious, exist in limited quantities and can be intimately intertwined. Have you ever longed to get away but lacked the money or time to take your ideal vacation? In our travels we have noticed that airports, surprisingly, are a favorite location for high-end watch displays. It is as if travelers

A seemingly everyday tableau of colorful watches arrayed here are all set to a time of 10:10. Why that time? Therein lies an intriguing mental mystery.

COURTESY OF SWATCH



Both 10:10 and 8:20 have a visually arresting shape for the brain (*bottom*). But one is much more commonly used. Why is that?

Not as cuckoo as you think: all clock sellers use the 10:10 display (*top*).

commonly must decide before imminent takeoff whether to pop into the newsstand to grab some gum and a copy of *Scientific American* or stop by the adjoining jewelry counter for a $10,000 Rolex. Who chooses the latter? We can't, unfortunately, although we do like to window shop. Next time you do, pay special attention to the watch displays and see if you notice anything unusual. You may see how advertisers exploit the intersection of time and illusion to sell their products.

Accurate Twice Each Day

Search for "watch images" on your favorite Internet browser, and you'll find something bizarre. Almost every watch is set to 10:10. What belief, what powerful insight, what shared brain mechanism could cause salespeople to hock their clocks with that setting? Is it that shoppers preferentially like to make purchases just after morning tea? Or, as conspiracy theorists have suggested, because 10:10 is the hour when John F. Kennedy, Martin Luther King, Abraham Lincoln or John Lennon was assassinated? Or when Fat Man and Little Boy burned the sky above Nagasaki and Hiroshima? Nope. All such proposals are factually incorrect.

According to the *New York Times*, the Hamilton Watch Company was among the first to set its products to 10:10—in the 1920s. The previous standard setting was 8:20. Some ex-

What powerful insight, **what shared brain mechanism,** could cause salespeople to hock their clocks with that setting?

GETTY IMAGES (*top*); SARUN LAOWONG *iStockphoto* (*bottom*)

Time may **fly like an arrow,** but it is your attention to time that advertisers care about.

ecutives now assume that the switch occurred to turn the watches' 8:20 "frown" upside down, into a "smile."

But to visual neuroscientists like us, all this speculation begs the question as to why clock hands were set to oblique 8:20/10:10 positions in the first place. It seems unlikely that pre-1920 watchmakers wanted their watches to frown. One possibility is that oblique watch-hand orientations are best at keeping company logos uncovered—but, if so, horizontal positions such as 9:15 or 2:45 would be even better. Because horizontal orientations have never been popular in watch advertisement, we can rule this idea out.

Could it then be that oblique orientations result in higher watch sales than do cardinal—or vertical and horizontal—orientations? The answer may well be affirmative and possibly explained by the neuroscience of perception and cognition. Scientists have long known that we can detect cardinal orientations more easily than oblique orientations. The visual cortex, moreover, responds to oblique orientations more weakly, as if they had lower contrast than cardinal orientations of the same physical brightness. In addition, fewer neurons are sensitive to oblique than to cardinal orientations. As a result, obliquely oriented watch hands are a tiny bit more difficult for us to see.

At first, this fact may seem like bad news for marketing timepieces, especially if you think that watch hands should be as visible as possible in ads. But neuroscience suggests that watch hands that are somewhat harder to see could be a benefit to clock sellers. To maximize the potential for sales, you really want your customers to rivet their attention on your product—and the visual challenge of seeing the oblique position draws that attention. Visual attention has the effect of enhancing the perception of difficult-to-detect image elements. Indeed, your attention is stronger when the object of interest is hard to see—such as watch hands that are oriented obliquely.

If Mad Men (and Women) intuited that obliquely oriented lines are attention getters, people in other fields may have arrived at similar conclusions. We looked for prominently featured clocks in fine art paintings and—voilà!—Marc Chagall used the time 10:10 in his famous series of clock paintings dating as far back as 1914, before the watch industry's own 10:10 preference.

Time's Arrow

Watch manufacturers are not the only companies that have toyed with the interaction of time and illusion in commercial advertising. When you use FedEx courier services to buy yourself some time, you may overlook the clever illusion hidden in the company's iconic logo: time's arrow, pointing toward the future. You can see either the white arrow or the FedEx letters, but not both at once, because one is always the background to the other.

The current FedEx logo was shortened from the earlier company name "Federal Express" and given a new snazzy illusory design element, the background arrow between the "E" and the "x." Did the company shorten the name to reduce the amount of paint needed for signage on its planes and trucks? That explanation makes no sense, unless the painters could use only one font size. Once the name was shorter, they could just

The watch industry was not the first to use 10:10 as an ideal setting for timepieces. Here is an example from artist Marc Chagall's clock series.

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FARHAD BERAHMAN *AP Photo*

FedEx incorporates a forward-pointing arrow into its ambiguous logo (look at the white space in the type). In languages that read left to right, the arrow points right (*upper left of image*)—and the arrow points left in languages that read right to left, such as Arabic (*truck*).

paint the letters larger to take up the same space and use about the same amount of paint. In fact, according to Linden Leader, the graphic artist who designed the new logo, the FedEx CEO specifically requested that the logo be easily legible on every truck from five blocks away.

Instead the change resulted from a thorough analysis of the company's name recognition in the market. Why might the new logo be more effective? One reason is that the arrow, a symbol that has special meaning to our cognitive system, helps to draw attention to the logo as a whole. Arrows indicate what scientists call "implied motion." Visual neuroscientists Anja Schlack and Thomas Albright of the Salk Institute for Biological Studies have shown that neurons that respond preferentially to specific directions of motion in the world are also activated by arrows pointing in those directions even though the arrows are not themselves moving but just represent the concept of motion.

The FedEx arrow pointing to the right signifies motion toward the future for those who write in English and other left-to-right languages. Moreover, because motion-sensitive neurons also prefer cardinal rather than oblique directions, the arrow competes powerfully with the FedEx name itself, so our perception vacillates between "FedEx" and forward momentum. In languages read right to left, the FedEx arrow points toward the left, such as in the Arabic version of the logo, consistent with the corresponding cognitive representation of time's arrow.

This same left-to-right effect works to express temporal order of pictograms grouped in sequences, such as in the famous representation of human evolution from prehominin to *Homo sapiens*. The direction of the sequence is fundamentally arbitrary, yet if you grouped it the wrong way, it would look like a time reversal.

So time may fly like an arrow, but it is your attention to time that advertisers care about.

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Food for Thought:

VISUAL ILLUSIONS

GOOD ENOUGH TO EAT

By Susana Martinez-Conde and Stephen L. Macknik

Face or food? The brain recognizes edible artwork on multiple levels

Are you impressed with meals that look like one food but are actually made of something else? Tofu burgers and artificial crabmeat, for example, are not what they appear to be.

It's actually an old trick. In medieval times fish was cooked to imitate venison during Lent, and celebratory banquets included extravagant (and sometimes disturbing) delicacies such as meatballs made to resemble oranges, trout prepared to look like peas and shellfish made into mock viscera. Recipe books from the Middle Ages and the Renaissance also describe roasted chickens that appeared to sing, peacocks redressed in their own feathers and made to breathe fire, and a dish aptly named Trojan hog, in which a whole roasted pig was stuffed with an assortment of smaller creatures such as birds and shellfish, to the amusement and delight of cherished dinner guests.

Unwelcome visitors were also treated to illusory food, but not for their own amusement. Instead they were served perfectly good meat that was made to look rotten and writhing with worms. Maybe not good enough to eat, but good enough to send your in-laws packing!

Food illusions are alive and well in the 21st century. Our buffet of contemporary lip-smacking illusions will appeal to both your eyes and your stomach … for the most part. We hope you'll enjoy the spread. Bon appétit!

SAME BOWL OF VEGGIES … OR IS IT? This still life by Italian painter Giuseppe Arcimboldo (*left*) includes the ingredients for his favorite minestrone soup and the bowl to serve it in. Turned upside down (*right*), Arcimboldo's bowl of vegetables becomes a whimsical portrait of a man's head, complete with bowler hat.

There are several interesting aspects to this illusion. First, why do we see a face in the arrangement, when we know that it is just a bunch of vegetables? Our brain is hardwired to detect, recognize and discern facial features and expressions using only minimal data. This ability is critical to our interactions with other people and is the reason that we perceive personality and emotion in everything from crude masks to the front end of cars.

Second, why do we see the face much more clearly when we flip the image vertically? The answer is that the same brain mechanisms that make face processing fast and effortless are optimized to process right-side-up faces, so upside-down faces are much harder to see and recognize.

ITALY, CREMONA, VEGETABLES IN A BOWL OR THE GARDENER/ DE AGOSTINI PICTURE LIBRARY/G. DAGLI ORTI/THE BRIDGEMAN ART LIBRARY

ERICH LESSING/ART RESOURCE, NY (*top left*); *SUMMER* (1563, OIL ON CANVAS), BY GIUSEPPE ARCIMBOLDO (1527–1593)/KUNSTHISTORISCHES MUSEUM, VIENNA, AUSTRIA/THE BRIDGEMAN ART LIBRARY (*top right*); *AUTUMN*, FROM A SERIES DEPICTING THE FOUR SEASONS, COMMISSIONED BY EMPEROR MAXIMILIAN II (1527–1576) (1573, OIL ON CANVAS), BY GIUSEPPE ARCIMBOLDO (1527–1593)/LOUVRE, PARIS/GIRAUDON/THE BRIDGEMAN ART LIBRARY (*bottom*)

A LOT TO DIGEST

Arcimboldo's composite heads demonstrate that, neuroscientifically speaking, the whole can be much more than the sum of its parts. Clever arrangements of individual fruits, flowers, legumes and roots become exquisite portraiture in their entirety, such as in the likeness of the Hapsburg emperor Rudolf II (*top left*), here depicted as Vertumnus, the Etruscan god of transformations, or in the artist's self-portraits as *Summer* and *Autumn* (*top right* and *bottom left*).

The brain builds representations of objects from individual features, such as line segments and tiny patches of color. You see a nose in the *Summer* portrait not because there is a type of cell that perceives noses but because thousands of retinal photoreceptors in your eye react to the various shades of color and luminance in that area of the painting. High-level neuronal circuits then match that information to the brain's stored template for noses. The output from those same photoreceptors also activates the high-level object-tuned neurons that recognize turnips, figs and pickles, which is what makes images like these so much fun to look at.

FOODSCAPES

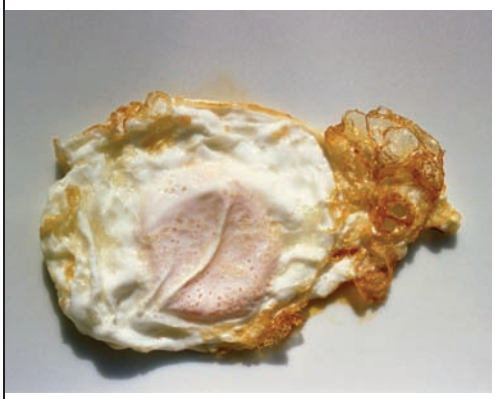
Art can be more than just a feast for your eyes. The image above looks, at first sight, like a painting of a landscape. But look closer. These are actual photographs of foods laid out to resemble various types of scenery and terrain. London photographer Carl Warner *(opposite page, top right)* arranges meats and vegetables to create each environment as if from a Brothers Grimm fairy tale and then photographs the scene in layers from foreground to background.

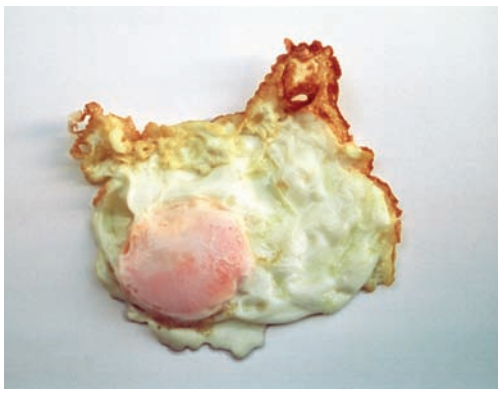
By using solely meats and breads in the image at the bottom right, for example, Warner captures the feel of old sepia postcards from the late 19th-century American prairie—complete with a breadstick-rail fence, serrano ham skies and a salami lane. Yum.

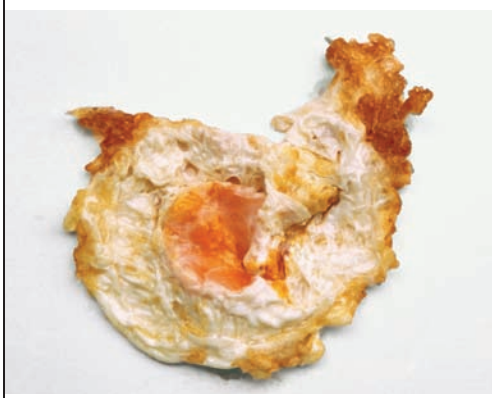
Warner's work is another example of how the brain puts together information from multiple streams. Visual data from every point of the image are converted from light to electrochemical signals in the retina and then transmitted to the brain—where individual features are constructed from the information in the image. These discrete features are broadcast to multiple high-level visual circuits simultaneously: circuits that recognize faces, circuits that detect and characterize motion, circuits that recognize landscapes and places, and circuits that recognize and process food are just a few of the brain paths that receive this basic information.

CARL WARNER

In Warner's art, both the landscape and the food-processing circuits are activated (the other circuits receive the information but ignore it as irrelevant because there are no faces, motion or other triggers in the image). And voilà! Our mind recognizes a delicious plate of cold cuts, as well as an overcast sky, in the same visual data.







CHICKEN-AND-EGG

Spanish artist Din Matamoro provides a unique perspective on developmental biology's most fundamental question: Which came first, the chicken or the egg? In Matamoro's fried eggs, ontogeny recapitulates phylogeny in an unusual and slightly unsettling fashion: the shape of each fried egg resembles that of the chicken that the egg would have become or perhaps the hen that laid the egg in the first place.

Such ambiguity illusions recapitulate visual perception as a type of ontogeny in and of itself. Objects, in this case chickens, are built in the henhouses of our mind from nuggets of visual information sent from the retina. These little visual giblets activate circuits that process animal shapes (birds in this case) as well as circuits that process food data. This kind of multiple-channel processing is at the heart of all ambiguity: the neural basis of ambiguous perception is two or more brain circuits that compete for dominance in our awareness.

EDIBLE POINTILLISM

Pointillist painters such as Georges Seurat and Paul Signac juxtaposed multiple individual points to create color blends that were very different from the colors in the original dots. But in a very real sense, all art is pointillism. In fact, all visual perception is pointillism. Our retina is a sheet of photoreceptors, each sampling a finite circular area of visual space. Every photoreceptor then connects to downstream neural circuits that build our perception of objects, faces, loved ones and everything else. Thus, vision itself is largely a pointillist illusion, colored by a tremendous amount of "guesstimation" and filling in on the part of our brain. It doesn't matter whether the painter uses brushstrokes or fields of dots to define surfaces.

The dots that compose these images of a cherry-topped cupcake (*left*) and Laurel and Hardy (*right*) are made from multicolored jelly beans, a technique that is not only clever but also delicious. Eat your heart out, Seurat.

COURTESY OF DIN MATAMORO (*top*); COURTESY OF KRISTEN CUMINGS *Jelly Belly Candy Company* (*bottom left*); COURTESY OF PETER ROCHA *Jelly Belly Candy Company* (*bottom right*)

ALL YOU CAN EAT

The hypothalamus, a small brain structure that sits at the top of the brain stem in the limbic system, controls emotional responses via the autonomic nervous system, as well as food intake. So it is no wonder that, as the characters in Lionel Shriver's novel 2007 *The Post-Birthday World* agree, everybody has strong feelings about food. Illusion artists using food as their medium have an unparalleled advantage to evoke emotions that enhance or destroy your appetite—unless you're a glutton for punishment, that is.

FOOD ART WITH LITTLE PEOPLE

Dramatist George Bernard Shaw said that there is no sincerer love than the love of food. If so, the miniature workers depicted here are living the dream. Of course, it's all a matter of scale.

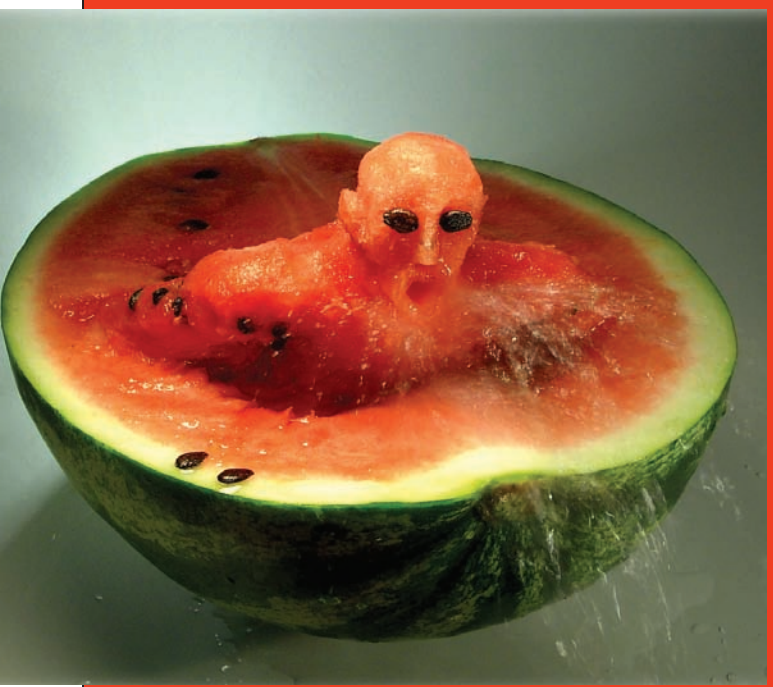
The juxtaposition of Lilliputians and huge fruit has the dual illusory effect of making the potentially normal-size people look tiny and the possibly typical fruit look supersized. It happens because the human brain uses context, the relative dimensions of nearby objects in the world, as a primary means to determine their scale and absolute size.

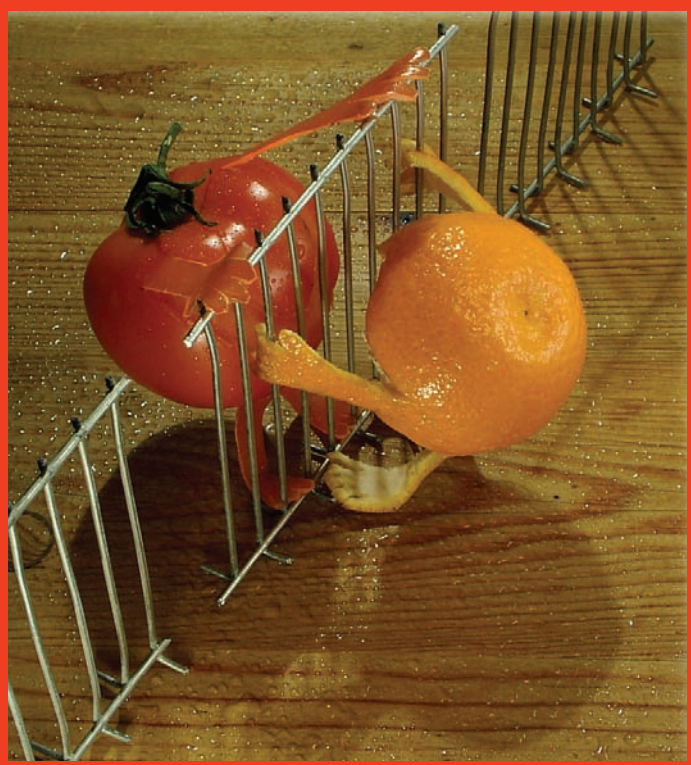
Think about it: we can't simply use the size of the projection on our retina to determine the size of an object, because the size of the projection depends on how far away the object is. A small, nearby object can have a retinal projection of the same size as a larger object that is farther away. To compensate for distance, the brain compares the sizes of unknown objects with those of known objects that are in the same scene. Juxtaposing tiny people with enormous fruit plays havoc with that scaling system, and both categories of object are affected.

NANCY J. KOCH *Getty Images (top left)*; GETTY IMAGES *(above, top right)*; EMIKO AUMANN *Getty Images (above, bottom right)*; COURTESY OF AKIKO & PIERRE *Minimiam (bottom)*

A SMORGASBORD OF ILLUSIONS

Peeling and paring can transform fruits and vegetables into a variety of amazing, strange and tasty illusions. Just in case your eyes are bigger than your stomach.





TAMÁS BALLA